SCIENCE
AND THE MEANINGS OF TRUTH

Studies introductory to asking what is meant today by physical explanation of Nature, by mechanisms of cause and effect, and by a claim that scientific knowledge is true

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ART AND SCIENTIFIC THOUGHT
TIME, KNOWLEDGE AND THE NEBULAE

To
JESSIE

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These were mutually antagonistic in much of recent philosophy,

Preface

MEANINGS OF SCIENTIFIC TRUTH

This essay arises from two convictions, firstly that recent self-criticism within physics allows or even demands a more definite meaning to the notion of Truth in science than has been hitherto possible, and secondly that any such meaning can be and must be expressed in language accessible to the general reader and not merely to the professional physicist or philosopher. But the treatment must not be 'popularized' in any sense of hiding or shirking the difficulties.

Faced with the fact that a world explored by our senses is explained in terms of electrons of a wave character and of a particle character alternately, or in terms of electromagnetic waves IN space, or in terms of curvature OF space, many suspect that scientific explanation may be true or untrue in some meaning not covered by the traditional progression from hypothesis to natural law through causes and a mechanism. Thoughtful general inquirers, with the philosopher as spearhead, ask the physicist what he means by the 'truth' of such explanations, and the more intelligent of the physicist's own students are not so readily intimidated into silence as are those general inquirers to whom mathematical language is a barrier. Now Mr. Bertrand Russell has not only been one of the most persistent philosophical observers of the physicist's progress, but he is notoriously the most readable and clearly expounding of writers, even to those who disagree with him: he attacks the most intimate of scientific problems without hiding either in a tangle of technicality or a haze of popularization. It is in the spirit of such writings, even if too inadequately to be recognized as a follower, that I am attempting here to adapt some of his clear logical analysis of the quantitative forms of reasoning, and apply them to the era of Heisenberg and Dirac in atomic theory. This era has proved somewhat destructive to the older logic of science. To describe physical science as a structure of relations

connecting events has been a commonplace ever since the writings of Whitehead, and was even implicit in the Lorentz, Einstein, Minkowski stage of the earliest Relativity: Dirac's more revolutionary approach to atomic physics, and Eddington's pioneer assessing of scientific knowledge as the apprehending of abstract structure, seem to me to make possible a more radical utilization of Russell's analysis of the forms of knowledge. Such analysis might be used in clarifying our minds as to what we really mean by the truth of a proposition or of a theory in physics. The development which I propose seems more hopeful than at the times of writing of any of these prime sources of inspiration, or of Broad, Jeffreys, Ritchie, and other recent pioneers in the logic of science, by reason of Milne's intervening attempt to reconstruct the foundation of scientific argument as a correlation of time-experiences of observers. I have earlier written critically and at some length of this last advance, in a book where Time is discussed as implicit in physical, astronomical, and philosophical inquiry: the contribution of Milne in the present essay is introduced as one item but only one of a variety facilitating a general critique and synthesis of the truthfulness to be claimed in modern physics.

A subject-matter so delicately poised on a borderline between science and philosophy becomes nonsense in any of the common confusions between these territories. To avoid the reproach—sometimes justified—that philosophers pontificate complacently about science while scientists trespass ignorantly into philosophy until the general reader is bewildered and swindled, I have introduced the problem and possible solutions along two main ways of approach. These I have separated as Part I and Part II, although certain notions such as 'structure and form', 'communicability of knowledge', 'coherence as test of truth', are used—with considerable difference—in both parts. I shall attempt to justify in the following General Survey why I have ventured to distinguish in Part I the LOGICAL and in Part II the PHILOSOPHICAL problems of scientific truth. The distinction may also indicate why until the final chapter or Part III, there is no step towards asking what is to be said of the truthfulness of the non-quantitative judgments of aesthetics and morals; in the end these must be brought into brief comparison with that quantitative use of sense-data which we call science, and its interpretation which we must call a philosophy of science.

General Survey

DISTINCTIONS BETWEEN SOME PROBLEMS OF TRUTH FOR SCIENCE AND FOR PHILOSOPHY

1

The property of being called truthful or erroneous characterizes not facts or the actual observations or recordings of the scientist, but his opinions; these are commonly embodied in the scientist's ways of arranging the facts to make theories based upon them. I shall suggest later that theories and hypotheses, and the verbal pictures or mathematical models by which we reduce facts and observations to connected systems of description and calculation, must be assessed as the provisional sorting of a certain kind of statement into a certain kind of pattern: it is to the propositions in this pattern that we aim to ascribe truthfulness or error. A typical proposition would be, for example, an assertion that a certain interaction between electron and electromagnetic field decides the occurrence of some measurable phenomenon in optics or radio, and it is not the fact of the physicist's measurement which can be untrue but the opinion embodied in the explanation.

It is a commonplace of all philosophical and commonsense query about modern physics, that the description of our external world in terms of these 'explanations' has become extremely unlike the description of the same world in terms of the perceptions to which our senses give rise. Nearly every recent writer on the philosophy of science has endeavoured to captivate or to scandalize his readers by pointing out that a lump of material is hard, cold, motionless, impenetrable, in the non-scientific account, but is a whirling swarm of widely separated electric charges in the scientific account; 'matter' reduces to points of singular intensity of electric field in empty space, its constituents totally inaccessible to the sight, touch, smell, hearing, of our individual explorations of the world.

The first question which the physicist must therefore expect to face from the outside critic is: 'By what right do you claim any degree of truthfulness in such a fantastic account of ordinary objects?' In spite of an enormous literature, both of the philosophical and of the popular orders, it is a rare and rash physicist who is prepared to answer this with conviction to-day.

I suggest approaching the question in the first chapter of Part I by a revaluation of the traditional logical sequence; this had usually been considered to lead from isolated facts to hypotheses capable of selection through disciminatory experimental evidence, and finally to the discovery and utilization of Natural Law. In this sequence a causal and mechanically describable scheme had satisfied pre-relativity and pre-quantum physics; but its inadequacy for modern needs raises with sufficient urgency the query of the present day, as to what more ultimately can test a theory and what can constitute the truth of some recent explanations, for example in terms of space-curvature.

But it is clear that such a beginning must inevitably appeal to two very differing interests, and that any answers to the questioning may be satisfying to one only of two kinds of person having different intentions when they set out to judge even 'scientific' truth. The working physicist himself, if he is not a philosopher too, wants a Truth which is measured by the extent to which the science is thereby advanced; to him an error is simply a false start, or any track subsequently to be retraced and abandoned with resulting retardation of progress. By 'progress' he will probably imply the coordinating of separate explanations into a connected single group which either brings aesthetic pleasure or facilitates control over natural phenomena. But by whatever compromise between sectional interests in electrical or optical or atomic research, he will certainly confine 'truth' to some such dependence on a provisional plan of importance to the state of the science at that epoch. In effect, his standards will be internal to his science; he will not, as physicist, be concerned to criticize his notion of truth by comparison with other modes of judging the validity of arguing about the external world, and above all he will not concern himself with speculations about any INTERNAL world of the scientist's own mind. Without pandering to the sense of superiority with which many scientists like to imagine that they are 'not metaphysical', he will

reasonably feel that a somewhat pragmatic convention is sufficient for deciding 'what will work' within physics. Part I is accordingly the physicist's reply to his colleagues and students and to his own intellectual conscience: it is not the philosopher's reply, though even the most strictly physical becomes a discussion in LOGIC as soon as the grounds for validity of an argument are to be scrutinized. It is not until Part II that the philosopher (who is certain also to be a logician and may happen also to be a physicist) begins to demand to know what scientific knowledge further means, as defining a particular mode of reacting to the external world, and not merely how it works within the framework of the physicist's own interests. It will not be until the final chapter or Part III that comparison with 'knowledge of truth' other than scientific is sought.

2

In assessing the present status of the logic which may be claimed to govern truthful argument within physics, it will be useful to trace with examples how 'mechanical exploration of cause and effect' characterized the emergence of the modern era from Newtonian times onwards. To begin with, it gave overwhelming advantage to gravitational astronomy over the mere geometrical representation of motions in the sky which had contented the ancients and medievals. It was from such successful instances of a field where effects were predictable that a general law of Causality became plausible, the criticism of certain aspects of which in recent atomic physics is leading to widespread revision of what is meant by scientific knowledge. The success of causal laws throughout dynamics, the molecular but not the atomic discussion of gases, and the dynamical theory of heat, followed by the profitable mechanizing of our notions of electrical conduction and the electromagnetic theory of light, carries physics up to the great triumphs which at the beginning of the century seemed a final crowning of such a very simplified world of matter and radiation. Drastic restriction of the possibilities in mechanical explanation only arose when the connection between matter and radiation was demanded, in the atomic theory of Spectra, optical and X-ray and now nuclear Spectra; the quantum laws which followed this restriction

brought ultimately a precise but narrowed scope to the previously accepted notions of Causality. Quite different criticism of 'cause and effect' sequences in Relativity has been followed by much controversy as to the comparative status of empirical and rational explorations in contemporary science: there seems to be intruding a novel scope for purely rational deductive reasoning, which a preceding generation had regarded as outworn and useless for the 'exploratory' phases of a research.

When we find that to-day 'scientific explanation' need not always include a mechanical model or picture in which cause and effect are traced with Newtonian precision, it becomes necessary to examine the attempts which have been made to rewrite the aims of physics in accord with this loss of confidence in the older grounds for certainty. The most striking originators in atomic theory, Bohr, Heisenberg, and the most revolutionary Dirac, have all been moved to make pronouncements about what physical science is really trying to do, which would have bewildered the confident mechanical physicists of the first decade of this century. Eddington, quoting Bertrand Russell's sense of Form in scientific knowledge, has rewritten much of the basis of scientific inquiry as a search for 'structure' or possibly a creation of 'structure'; this conceivably will replace our ancestors' obsession with seeking 'things'. It seems that if the elements of such formal structure can satisfy what Dirac demands, their genesis may be important to compare with Whitehead's genesis of physical concepts as expounded as early as 1920 in his geometrization of common quantitative experience. A profitable approach to the current meanings of knowledge and truth in physics may thereby be opened in directions hitherto not available. We may in the future have to aim at arranging our experimental facts as a formal pattern in symbols whose mechanical significance we neither know nor care to know; but the labour may be quite as worthy as before, and more successful in approach to a new standard of truthfulness than when we claimed to 'know what an electron really is'.

The utilizing of Russell's most general notions of the formal structure of all logical systems, becomes feasible to a degree not possible even to Eddington or Dirac a dozen years ago, since Milne in 1936–40 began to show how much of physical foundations could be deduced from the rational logical laws essential to the correlat-

ing of different observers' experiences of events and their ordering in time sequences.

I propose to suggest a principle wider than hitherto for covering all that seems lasting in these developments, namely that scientific approach to truth is essentially the rearranging of events from individual time-sequences into transformable patterns whose selection must make them 'communicable'. By communicable I shall imply a generalization of the requirement taught us by Relativity, that the transformations shall become adequate over all varying circumstances of all conceivable observers. This demands in progressive achievement a science independent of all possible individual conditions, the germ of which is again traceable to Russell. The test for truth in a physics so aimed becomes a test of the 'coherence' between the differing statements obtainable after all possible transformations of a scientific proposition. Coherence of the patterns from quantitative experience will be discussed in the final portions of Part I, and it is possible that this importation from a logic which has not recently been fashionable may serve to avoid some of the difficulties of the most recent physics.

For readers whose acquaintance has not been in physics, introduction to the relevant technical material is included in each chapter in Part I.

3

Some care is needed against mixing of categories, in claiming to discuss in Part II a philosophy but predominantly a philosophy of science; Part I had been confined to science and to the latter's logic alone, the introduction of such philosophers as Russell and Whitehead in Part I bringing only their contribution to the notion of the logical forms used in the structure of physics. Some workers deriving from Wittgenstein's development of the Cambridge school would confine profitable philosophy almost entirely to the critique of scientific concepts; others at a different extreme would consider the analysis of science so trivial as to provide only minor general philosophic interest. Between these I would appeal for the following distinctions among the ways in which scientific truth might be discussed.

The treatment in Part I has analysed some of the inadequacy in the traditional logic of the inductive sciences, an inadequacy forced upon them by recent atomic physics, relativity, and cosmology: the remedy suggested was also within logic, as scarcely impinging on any wider philosophical problem than the rearrangement of convenient and legitimate methods within science. This remedy was to replace the older procedure of 'progress from hypothesis to natural law on a basis of mechanism and causal sequence' by a more cautious and adaptable procedure of 'selecting or constructing a pattern of relations between temporal experiences of individuals, that pattern being tested by "coherence" until universally "communicable" and thus true'. In this suggested procedure the commonplaces of inductive logic such as measurement, symbolization, and simplification, all survive, and their embodiment into formal Transformations becomes important; but the notion of hypothesis and law becomes somewhat blurred, the turning from the one into the other becoming less sharp, less decisive, and perhaps less desirable than our ancestors thought in their easier age of primitive science.

But any such revised 'methodology', or analysis of scientific aims and processes, derives original inspiration from the source to which Eddington attributed his recognition that physicists study structures rather than things, namely the English Realist philosophers, of whom perhaps the most important for science are Bertrand Russell and C. D. Broad. Their central problem was the problem of Perception: they were interested in the obvious and tantalizing gap between what our senses provide and what our minds construct thereon. Now this gap stretches most widely and disconcertingly of all, when the sense-data of the physicist's measurements are finally attributed to an underlying population analysable only as being the elaborate set of concepts woven into pattern by the atomic theorist or the relativist. So the particular detail stressed in this essay, the aspect of physics as the pattern based on sense-data in the individual sequences of observers' time-experiences, seems to offer unusual hope towards a philosophy of what such scientific knowledge might mean and by what criteria its truth is to be tested. This may be a model problem in theory of knowledge, more likely to be within reach of our generation than the wider questions of the meaning of all knowledge which have been left

inconclusive between the labours of the great philosophers down to the present day.

An unexpected feature of our treatment of this particular and restricted problem of the philosophy of scientific truth, is that while it derives its emphasis on Form and Structure from Russell and the English Realists of this century, it has also, I consider, an intriguing possibility of deriving much from a test of truth which is essentially a test by 'coherence'. This surprisingly suggests the Coherence theory of all knowledge, which belonged to the Idealist philosophers, against whom Russell and the Realists were the indignant reaction. It will be very necessary in Part II to see where the possibilities and limitations of the realist and idealist theories of knowledge might so cancel, in the particular case of scientific 'truth', that in this domain alone the formal elements of the one become compatible with the coherence test of the other.

4

To claim that complete agnosticism about the external world of Nature is only escaped through coherence of physicists' patterns, is not an attempt at a restoration of traditional idealism to replace realism in general philosophy, in which wider domain conceivably neither will ever be conclusive: for in philosophy of physics the coherence which is significant is not the idealist's coherence of mental states.

In fact, by restriction to those kinds of sense-data and that kind of knowledge claimed by physical science alone, Part II avoids any direct intrusion into the philosophies which are designed to cover the totality of experience. In a final chapter, however, segregated as a Part III, there are pointed some of the contrasts with philosophy of aesthetic and moral judgments—together with some possible contacts. These are domains in which Time implies not solely the physical sequence of sense-data but the worlds of memory and imagination contributing to personality and not merely to the external structure of Nature, domains where the quantitative ceases to be the only relevant judgment.

Such considerations may serve to outline what kind of a philosophical problem concerning science is attempted in Part II, as sequel to the mere logical rearrangements within physics attempted

in Part I. We shall be bound to the double question, firstly what theory of knowledge for the case of temporal sequences of sense-data can be suggested BY the topics of Part I, secondly what theory of knowledge adaptable FROM general epistemology will be legitimately applicable to the results obtained in Part I.

PART ONE

METHODS OF APPROACH TO TRUTHFULNESS IN THE LOGIC OF SCIENCE

Chapter 1

CRITIQUE OF SCIENTIFIC METHOD

(I) THE OLDER SEQUENCE FROM HYPOTHESIS TO LAW

A physicist or chemist or biologist of the Victorian or Edwardian eras, when asked upon what grounds he claimed any truthfulness in ascribing observed phenomena to an underlying world of atoms and molecules and electric charges, had little reason to quarrel with the accounts of 'scientific method' by which 'validity of argument' was commended in the final pages of any current text-book on elementary logic. It is a feature of the present discussion to recognize that attitudes to our surroundings implied in such method may alter under the impact of recent physical discovery, and that these alterations may be more radical than any in the formal canons by which the validity was guaranteed. In fact, when modern physics affects the logic of our approach to the external world, it affects more drastically the scientist's mental imagery than his formal rules—his interpretation of what kind of truth he seeks rather than the selection of steps to be taken in the details of pursuit. This will require us some day to cease isolating the logic of science from the psychology of the scientist's own mind, an almost untouched subject.

The traditional logic, or analysis of our right to draw conclusions, had stressed a contrast between the INDUCTIVE reasoning of observational and experimental sciences and the DEDUCTIVE reasoning of mathematics and much social discussion: deduction may typically be represented by the fact that, if a certain general statement be true, then one particular statement is CERTAINLY true if it can be shown to be included under the general, whereas induction typically proceeds from many particular statements observed to be true, towards a generalization which may with varying degrees of reliability be accepted as PROBABLY true.

The canons of validity for deduction had stood with only trivial modification for centuries and can be traced even to Aristotle; whereas inductive methods seemed to develop with the earliest systematic experimenters of the modern era, traditionally expounded by Bacon. They were notably formulated by J. S. Mill in the nineteenth century in a manner useful to his contemporaries but inadequate to present needs of scientific research. Attempts were occasionally made by working scientists to rescue the 'laws' of induction from their brief and sometimes contemptuous treatment at the tail-end of the logic text-books, and these writers succeeded in enforcing recognition that experimental scientists might well collaborate with philosophers when logic is to be redrafted: the most serious contributions were perhaps the treatises of N. R. Campbell (1921), Ritchie (1923), and Harold Jeffreys (1931). Meanwhile philosophers began to query the uncertain status of induction, notably C. D. Broad in 1918, and one systematic treatise on logic (W. E. Johnson, 3 vols., 1921–4) has evolved an interrelatedness of all forms of reasoning, deductive and inductive, or rather 'demonstrative' and 'problematic', under wider and more reliable and understandable principles. These latter bid fair to include the work of the experimental scientific researchers of all kinds, and also of those, notably Bertrand Russell, who had evaluated the rational meaning of mathematical argument. He had not shrunk from justifying the beloved science as 'the study in which we neither know nor care whether what we say is true', in reference to the hypothetical character of the propositions constituting the premisses of any purely mathematical deduction.

The working scientist's attitude is not primarily an interest in the logical forms of his reasoning: nor is he readily drawn to interrupting the progress within a science to raise queries as to Truth. 'Truthfulness' is not a word used very freely within scientific circles, and when introduced it is often uncritically made to mean 'that which is sought and which it is hoped to guarantee by using Scientific Method'. Empirically it can often be adequately judged by the criterion of allowing an ever-widening scope of explanation to an ever greater proportion of hitherto isolated phenomena, thus tending to aesthetic satisfaction of a fundamental human instinct of curiosity or tending to facilitate a profitable control over natural phenomena. When attempts are made to break a vicious circle of

defining truth as the target of scientific method and science itself as a pursuit of truth, the conception of 'explaining facts' seems common ground to many divergent interests: these will include some of the most revolutionary aims of present-day physicists. A similar conception will also serve the workers in many other sciences who ultimately benefit by methods devised for physics, and perhaps all the optimistic explorers from Leonardo da Vinci through Newton and Faraday to Rutherford, for whom Nature was more alluring than intimidating and whose labour was not quite inadequately expressed by the commonsense of Mill's 'methods of experimental inquiry'. Explanation—however ambiguous we find that word to-day—would not proceed far from any starting point unless it were based in practice upon a strategy of varying separately the selected factors of an experiment and eliminating those which are irrelevant; and that procedure sums up not only Mill but more modern analyses. But what is altering nowadays is the degree of finality expected at the various stages, and also the kind of mental picture into which 'explanation' is allowed to crystallize: our experimental technique in the physical sciences outgrows itself yearly, far faster than our logical technique. However, it may well be claimed that our logical and philosophical THEORY of scientific knowledge and truth ought not to lag behind as lazily as hitherto, now that the thoughtful scientist's attitude of mind is in a state of flux as to what a 'truthful explanation' means.

In particular, I shall urge in later chapters that the target aimed at in accounts of the physical universe is rapidly changing through criticism of the conceptions of 'mechanism' and 'cause', and that distinctions in traditional logic between hypotheses and natural laws must no longer imply sharp and irreversible transitions from the tentative to the final. If the mathematician has recognized that 'form' interests him to the exclusion of any relevance of 'truth', the physicist's 'truth' may itself become very much more convincing through a radical reorientation towards the logical notion of 'form' which in the work of Russell and others has revolutionized the interpretation of the older logic, if not of its rules. In the present section (I) of Chapter 1 the briefest survey of this older logic of the inductive sciences will suffice to outline what the remainder of the chapter is to assess critically in its historical successes and recent failures, prior to the reconstruction arguments of Chapters 2–5.

The isolated and often uncontrolled observations from which the scientific mind begins to find raw material, must be recorded, and when classified and free from the more obvious irrelevancies they readily suggest a 'hypothesis'. For a stage in science not so primitive as the pre-Newtonian and not so introspective as the post-Einstein; such hypothesis nearly always took a recognized form: it was an imagined reference of the data from the sense-perceived objects to other and unperceivable objects which were regarded as 'causes' but whose behaviour was to be of a similar kind merely on a smaller scale—many millions of times smaller. Typically, and very often successfully, explanation of large-scale facts was in terms of an imagined underworld of atoms and molecules; these were supposed to obey laws of mechanism, and to exhibit cause and effect such as had been found to hold when the larger objects perceptible by sight, hearing, touch, etc., moved visibly and tangibly about the obvious world.

Such hypotheses, for example that collisions between molecules acting like submicroscopic billiard balls could explain the conduction of heat in a gas, were capable in turn of suggesting discriminatory experiments which led either to their rejection or modification or 'verification'. For instance it became necessary to attribute to the balls a non-spherical structure or a degree of elasticity. Verification could be claimed when application of known mechanical and causal laws to the supposed 'model' was able to predict some hitherto unobserved behaviour in the large-scale material object under experiment, and when the prediction worked out for the molecular model agreed with subsequent discovery of that particular behaviour in the larger object accessible to direct sense-perception.

A verified hypothesis was by this means transfigured into certainty, and it was considered that a Law of Nature had been discovered, although it was frequently found that a very different hypothetical model was capable of yielding the same prediction: hence the imagined 'model' of molecular structure was not always unambiguous or unique.

In this scheme of inductive logic there could be many minor variations: some writers inverted the distinctions given to degrees of hypothesis, theory, law, in the tentative explorations towards explaining what we are to suppose must underlie observed pheno-

mena. These variants on the theory were in effect trivial compared with recent more drastic querying of 'mechanism' as the legitimate requirement and the criterion of 'scientific explanation'. Of an intermediate degree of importance was the salutary caution of those (for instance Kirchhoff and Mach) who preferred 'constructive description of fact' as a term claiming all that ought to be claimed in any generalizations which were to include a 'why and how' of natural phenomena. The controversy as to whether Mechanics is merely descriptive or not was a major issue at the end of the nineteenth century when James Ward wrote *Naturalism and Agnosticism* and the remnants of Victorian materialism still lingered among the uncritical, and the arguments were summed up with characteristic brevity and clarity in Bertrand Russell's early *Principles of Mathematics* (1903). All such controversy seems dwarfed to-day by the enlightenment of Relativity and the Quantum developments of physics, since not merely the significance of mechanical description but its desirability and possibility are questioned to a degree undreamed by the Victorians.

The scientific researcher who ordinarily utilizes all these inductive procedures, is not always satisfied by the somewhat circular justification which we stigmatized above as 'science defining its truthfulness by scientific method', and he will generally appeal to 'Uniformity of Nature'. Now unless the experimenter had at least some confidence that the conditions under which he observes a fact to-day would, if precisely reproduced, allow him to make identical observation to-morrow, or allow some distant colleague to make it identically at any other time, then it is clear that research would be so haphazard that few would find in it the exhilaration of which we all boast. But the status of any 'Law of Uniformity' to emerge from that confidence is not always so clear: apart from that feeling of comfort and security for research, it owes too much to an anxiety for confronting the formal logician with something not degraded in comparison with the rigid frame of inference which belonged to the deductive sciences of mathematics. These traditional schemes of deductive inference involve a Major Premiss, Minor Premiss and Conclusion. Typically: 'All men are mortal, so-and-so is a man, therefore so-and-so is mortal,' is the crudest example. In comparison with this undoubted but somewhat facile approach to truthful argument, exploiters of the reverse

process in the experimental sciences who generalize from particulars instead of particularizing from a general major premiss, suffered a feeling of inferiority. This feeling obtained some relief by claiming the 'uniformity of Nature' as a grand single major premiss sanctioning all the inferences of inductive science. It was perhaps a pity that they were not content to recognize that the novel but merely problematic 'truths' of increasing generality, sought by empirical science, possess aesthetic and practical attractiveness not inferior to the rigidly certain but often tautologous truths of decreased generality sought in geometrical inference. A healthy lesson is to read such a synthesis of deductive and inductive principles as is evolved in W. E. Johnson's treatise referred to, for of course any protracted research includes deductive sequences as well as inductive.

This somewhat emotional urge, which I suggest underlies many attempts to confer logical status on 'uniformity of Nature', may be the psychological basis for a 'Law of Causation' for centuries occasioning controversy. These controversies range from the fundamental doubts expressed by Hume in the eighteenth century, to the merely convenient and classificatory distinctions such as Eddington's 'causation' and 'causality' which I shall not pursue here. Bradley and the Oxford logicians, who followed Hegel's leading and deny 'Reality' to any concept of which we have not yet succeeded in formulating an unambiguous account, have taken as a gift the very confused statements about Causation made by philosophers throughout history. It will be made clear from examples in sections (II) and (IV) that the notion of Cause and Effect has important but limited validity in modern physics; when the term implies utilizing an empirical confidence that similar antecedents may successfully be expected to be followed by similar consequences, no scientist has any quarrel with it. The logicians' difficulties in establishing a rigid formulation of Causation then seem trivial. But it will also become clear that any more ambitious attempts in blind faith to insist upon a causal chain, as necessary to the pattern called 'scientific explanation', have been shown to be seriously misleading after what we have learnt from the Einstein and Heisenberg eras of Relativity and atomic research.

With this disillusionment over notions of Cause and of mechanism, there have been public statements grossly overestimating the

philosophical implications of such changed attitude, and even prophesying effects in theology: these can be left to be killed by common sense, but within physics itself we shall have to notice that the traditional sharp transition from uncertainty of hypothesis to certainty of Natural Law has with the modification of Causation become blurred. These notions seem now to have something of the character of a dream from a simple-minded age. I shall venture in Chapter 5 to suggest a more general term for the aim of science than discovery of Natural Law, to carry a more practically and philosophically satisfying test of truthfulness, in closer accord with the needs of atomic physics, Relativity, and modern logic. Meanwhile the traditional sequence of causal mechanisms must be pursued into examples and scrutinized, (II), (III), (IV), before the balancing of success and failure can reasonably reinforce such call for reorientation of the meanings of truth in scientific explanations.

This scrutiny must also cover the inadequacies of recent controversy as to the rightful functioning of induction and deduction in modern science, (V), (VI); but most of all it must expose the inadequacies in the psychology of the scientist's attitude. Our mental imagery is changing too rapidly to have been clearly followed in these years, and we have not only been mistaking the transitions between the categorical and the hypothetical in our Victorian usages of scientific logic, but have clung to a desire for mental picturing of physical processes which Dirac has now taught us to outgrow. Truth in science will become most of all unrecognizable to the inheritors of Victorian rigidity when we abandon the lust for attaching little images of large-scale perceptual objects to the symbols of modern differential equations. Eddington's attempts to persuade the scientific world that this abandonment is salutary, have been contaminated by some philosophical commitments which I am unable to share; but his recognition that what we learn to 'know' in science is 'structure', not 'things', I hope in Part II to pursue into some unexpected philosophical implications. Not merely truth for the scientist, but the scientist's contribution to the meanings of truth for all thinking minds, must be the subject of careful inquiry in all scrutiny of the modern physicist's attitude to environment.

CRITIQUE OF SCIENTIFIC METHOD

(II) SUCCESSES OF MECHANISMS OF CAUSE AND EFFECT

It will be profitable at this stage to recognize that recent physics is not the only crisis in scientific history whose analysis is important for the meaning of knowledge and the significance of its truth. The genesis of the modern era is often taken to begin with the replacement of an erroneous view of the solar system. Previously a central earth with sun and moon and planets circulating around it had been postulated: this had to be superseded by the correct notion of a central or focal sun with earth and planets circulating, some of the latter in turn surrounded by circulating satellites of which our own moon was at that time the only obvious example.

Now the earliest serious speculations had already long grasped the obvious tracks across the sky as circles projected, but until the end of the Middle Ages the principal component as a common one due to our own daily rotation had not been correctly separated out from the periodic orbits of earth and all planets around the sun. Nor had it been realized that the orbits are elliptical, though in most cases, save the recurrent comets, not very far from circular. The ablest pre-modern attempts, dating from Ptolemy and elaborated into ingenious detail by the Persians and Arabs and medieval Europeans their pupils, were based upon the recognition that the complex track of a planet could not be at all accurately represented by a SINGLE circle centred at the earth. Two alternatives gained currency, either that the planet revolved in a small circle which itself rolled upon the larger earth-centred circle, or that only one circle was required but centred not quite at the earth.

It is a remarkable thing that these combinations of circular possibilities actually did represent the positions of the observed bodies in the sky to within one minute of arc: so the gravest error of the assiduous Moslems on the Greek model was not so much in fitting a geometrical picture to the facts (often since accepted as the aim of any theory) but in their lack of any 'explanation' which discovery of a 'physical cause' might provide for that very tolerable degree of fit. The greatest advance made by the era of Copernicus–Kepler–Newton was that the novel representation in terms of ellipses with sun, not earth, as focus, allowed a generalization covering not only these but many other facts concerning bodies in motion under one another's influence.

After the Copernican replacement of the geocentric by the heliocentric, the way was paved for Kepler's geometry which gave remarkable information about the necessary distances, etc., of planets; but also the first historical instance of a 'physical' law (Newtonian gravitation) became a possibility and for centuries was the standard instance of Cause and Effect. It was recognized that all the complex geometry of the solar system was bound to follow if two isolated masses are in motion under a mutual attracting force varying according to the inverse square of their distance apart, and prevented from diminishing that distance by the inertial tendency to move at a tangent against the radial attractions. Such use of the Newtonian gravitation required also that basis of modern views, the Newtonian definition of 'force' as product of mass or inertia and acceleration or CHANGE of motion.

This first instance of a hypothesis appealing to physical cause, in a science no longer content with geometrical representation, was built into modern mechanics with its skilful generalizations and the far more 'applicable' mathematical technique of Lagrange's and Hamilton's equations. Its verification includes the classical triumph of predicting the position and properties of the hitherto undetected planet Neptune, by applying gravitational calculation to the unknown mass which must have been 'causing' the known planet Uranus to deviate from its normal path.

For our purpose the most significant applications of such 'causal' laws, based on the conception of inertia and this 'acceleration' defining 'forces', have been in molecular and atomic physics and electricity: for there we meet the borderline at which the most striking successes are reached and then in turn come to a halt indicating the limitations of causal mechanism. The first development in the late nineteenth century was to cover the motions of the minute and invisible particles of which any gas consists; if these are in continuous random movement (at an ordinary temperature about 1·8 kilometres per second for apparently stationary hydrogen), the hypothesis that Heat and other forms of energy are interchangeable allows many of the mechanical and thermal properties of gases to be quantitatively predictable from the laws of collisions between these molecules. The successes include the phenomena of 'transport', or transmission of heat, of momentum, and of the molecules themselves, through the gas: conduction, viscosity, and

diffusion, were therefore 'explained' in this sense. The meaning of this word 'explain' was then that rules supposing 'forces' to 'cause' the observed facts could be formulated by applying Newtonian calculation to a postulated swarm of miniature particles, about no one INDIVIDUAL of which any information was available.

A wider range of facts in the large-scale observation of gases was next covered by ascribing numerical degrees of 'softness' to the molecule, which had first been pictured merely as an impenetrable billiard ball a million times smaller. The point at which this 'causing' of large-scale facts by a mechanism of extremely small-scale particles breaks down, is where the ascribing of elasticity and structural asymmetries to the molecules demands a rule of how they exchange energy in their rotations and vibrations as well as linear colliding paths. It became evident, especially when the molecules break up into atoms and the atoms lose some constituent electrons, that there were novel rules of energy exchange which did not appear in the 'miniature billiard ball' model and had no Cause in Newtonian mechanics. The novel rules had to be imported as *ad hoc* and took the form of 'quantum' restrictions; in particular the energy, which on the classical Newtonian system was supposed continuously available, was now only regarded as capable of liberation in multiples of some very small amount or 'quantum'. This notion, debarring the ordinary concepts of mechanism from the smallest individual examples of material behaviour, will be referred to in more detail in (III) and (IV).

In the twentieth century the mechanics of a swarm of colliding particles as 'explaining' apparently immobile matter was extended to the thermal and electrical conduction of solid metals: the 'gas' in this case is the stream of free electric charges or electrons, each 1/1850 of the mass of the smallest atom, threading their way between the more localized but vibrating atoms of the metal. But the resemblance to the 'billiard ball' became thereby even more remote; and the mechanism, while correctly predicting the connection between conduction of heat and of electricity for pure metals at ordinary temperature, failed to account for the fantastic occurrences at low temperature and the disconcerting but useful effects of intermixing small traces of alloying impurity. The contradictions between mechanical theory and fact were again resolved in the worst cases by importing into the theory a 'quantum' restriction.

The success and the limitation of mechanisms traceable to causes is even more striking when we turn from the physics of 'matter' to that of 'radiation', which involves the conception of energy transmitted through entirely empty space—for instance from the sun. The need to dissociate a criterion of truthfulness from an ability to trace a causal mechanism will here point even more inescapably to our later view of physics as 'pattern without demand to know of what THING we discover the structure'. Quite early in the history of modern optics, more than a century ago, it became possible to predict verifiable facts as to the distribution of light and shade around opaque bodies, by assuming as explanation of light 'a progressive wave motion carrying energy by SOMETHING vibrating in SOME medium'. The analogy with grosser elastic waves in solids and liquids and gases is perfectly precise, the form of the Differential Equation of all waves being reproduced and similarly soluble for radiation from the sun, and also for water ripples and vibrating strings and membranes and earthquake waves in the earth, *mutatis mutandis,* since some of these waves are transverse and some are longitudinal. In the case of Radiation (including Light, Heat rays, X-rays, and Radio) the 'something vibrating' is undoubtedly a pair of alternating electric and magnetic quantities, not anything material at all: in the particular instance of Radio, where the 'wave-length' is very long compared with that of Light, these electromagnetic quantities show up in direct detection, but in many of the other instances the evidence is indirect but as rigorously convincing.

But when we ask for the 'some medium to carry the waves', which would be essential if the mechanical chain of causal argument were to be followed, we reach the limitation of the argument. Sound and elastic waves require at least thin air when not carried in solid or liquid, but between us and the stars whose electromagnetic radiation we receive as light, there is no depth of even the most fancifully tenuous gas. The Victorians confidently filled in the intellectual hiatus, demanding the 'nominative of the verb to vibrate' and so defining the 'ether'. Only the revelations of the Relativity experiments proved that under no possible circumstances could this ether exhibit any property other than those of empty space, and the concept thereafter dropped out of the scientific dictionary. I shall attempt to justify in subsequent chap-

ters the epistemology by which we are nowadays content to say 'we describe as an electric vector that which we find vibrating, but we know nothing whatever of any medium in which the vibration is to be supposed to occur'. This opens an unfillable chasm in any mechanical explanation, in contrast to the Newtonian optimist's confidence that he must invent an ether to complete a tale of which he was sure he knew the last word. We shall even have to approach the agnosticism that 'vibration' may be a symbolic term, whose contribution towards truth is its use in verifiable predictions rather than any blind faith in its physical reality: for there are now other experimental facts, in which radiation behaves not at all like a wave but like a hail of particles—though the particles are not material and resemble the 'quanta' already met as localized minimum amounts of exchangeable energy. We have reached the stage at which a causal mechanism is at the same time true and untrue, so that a closer scrutiny of this type of scientific explanation of Nature will be needed.

(III) INADEQUACIES OF THE NOTION OF MECHANISM

It will now be possible to follow the hint already emerged in the preceding section, that in atomic and electronic phenomena the mechanisms whereby 'forces' are found to 'cause' accelerations in 'matter' cannot be traced beyond certain limits in size or into any pseudo-material 'ether'. The discussion now splits up; in section (IV) it will be convenient to distinguish between saying 'causal sequences are inaccessible' and saying 'we have no ground for considering causal sequences to exist'. But in this section (III) attention can be confined to those aspects of mechanism which were essential at the Newtonian stage but which lack meaning in recent physics, and which mainly concern the rapidly fading distinctions between matter, radiation, and space. Until the present generation there was little suspicion that these terms could overlap: they might have been the physicist's Categories, without prejudice to the Kantian history of that word. Either matter or radiation could be said to 'occupy' space, but concepts involved in the description of each of the three were mutually exclusive. Throughout the present generation, however, much of atomic physics might well be

labelled the attempt to know how matter gives rise to radiation, and much of the general theory of Relativity has spent itself (perhaps fallaciously) in an attempt to know how properties of 'space' expressed as 'curvature' can give rise to the behaviour of matter. It is conceivable that some at least of each effort has been misdirected by unconscious survival of the Victorian demand for 'explanation' to mean the tracing of a mechanism, the same demand which had led to ascribing spurious material properties to an ether that is merely space.

A main source of misunderstanding has been the older scientist's desire to distribute the identification of the topics of his discourse with the ancient philosophical Categories of 'substance' and of 'space'. Substance, as appealing to the scientist under the guise of his own 'matter', was most readily conceived as summing up all the 'objects' whose movement within space was describable by the laws of mechanics. The essential characteristic of such matter was its inertia or tendency to 'remain stationary or in non-accelerated motion unless subjected to forces, such force being measured by the product of acceleration and mass', as expressed in the Newtonian foundation of dynamics. This foundation was completely satisfactory when only objects of magnitude accessible to sense-perception were studied, and I have already discussed here the remarkable success of following such laws into the submicroscopic region of gas molecules and the moderately large astronomical region of the solar system. The disruption of substance in its molecular form, however, yields atoms and electrically charged particles, the electron and the heavier primitive constituents of all matter, which were by extrapolation regarded also as having some substantial properties however small the individuals might be. Any such regard would demand from them their mass or quantitative measure of inertia, and in fact this was readily obtained, not by the gravitational comparisons of a gross laboratory balance but by observing their response to applied force, in particular their accelerations and the bending of their paths under magnetic and electric forces themselves assessable on a Newtonian scale.

Two discoveries then intruded to enforce an overlap of the exclusive categories of the material and the non-material; both discoveries attain rationality in the earliest of Einstein's Relativity theories in 1905, but both are quite convincingly guaranteed by

laboratory measurement and by astronomical evidence as to the stability of the stars. The overlap of material and non-material attributes which they imply is genuine, and not the mere imaginative ascription of material property to an ether by our ancestors, since these new discoveries depend upon measurable inertia. Firstly it was found that the inertia or mass of the smallest bodies, typically the electron capable of the highest speeds, is no longer a constant as required by the Newtonian conception; it increases measurably with velocities of extreme magnitude, and would seem verily to preclude any material body ever reaching the speed of light. Secondly, radiation, the carrier of energy in total absence of any substance between here and the sun, nevertheless does possess an inertia of its own. In fact the mass and therefore momentum of radiation is quantitatively detectable in a delicate laboratory apparatus and is the only agency to stabilize the gravitating bulk of the largest and most diffuse stars.

But if mass or the material hallmark of 'substance' can thus alter with velocity, that is to say with time-rates of alteration of spatial position, and if radiation itself exhibits the property of inertia though it represents the non-material energy which 'substance' was supposed to emit across a space which has no substantial property at all, then the fundamental concept of mechanism as motion of substance within space and of vibrating media within space must lose its basis of mutually exclusive categories: matter and emptiness and propagated energy exchange some of the notions invented for each.

A further incidental interpenetration of the older terms belonging to 'truthful explanation' arose, as soon as sizes could be roughly ascribed to the constituents of an atom; it was found that any 'volume' conceivably allowable to the electrons and the nucleus must be a million million times smaller than the volume 'occupied' by the atom. In fact we have the fantastic situation that the densest matter is almost nothing but empty space: the character of 'electrically charged' appears to carry with it the 'inertial' character which had been the essence of the mechanist's world of substance, but over as small a fractional area as is occupied by the rare planets scattered throughout the empty space of the solar system.

But a more radical interpenetration of concepts until recently separated is the ascription of 'wave' properties to electrons and

other 'particles', and the ascription of 'particle' properties to radiation which our fathers were perfectly certain was entirely a 'wave' manifestation. A set of physical phenomena is describable as due to waves, if use of a certain differential equation giving periodic fluctuations in a quantity's amplitude enables facts such as the 'diffraction patterns' familiar in Light and Sound to be predicted, and if these predictions are then verified, e.g. on a photographic plate. From about 1925 onwards it was found that a stream of electrons does yield such 'diffraction pattern' just as Light or X-rays had always done, though on a scale commensurate with the electronic velocity which is not that of radiation. Many properties of electrons have since been correctly predicted by applying to them a wave-equation instead of assuming they are particles of matter. Perhaps it is truer to say that all constituents of 'matter' can in some of their character be profitably treated as non-material wave phenomena. Conversely, some of the properties of a beam of light had exhibited a minority tendency to contradict obstinately all predictions based on the usually successful wave theory, but have become intelligible by treating the beam as a hail of particles. Such particles are not to be regarded as material, but are localized 'regions of high energy content, or carriers of energy' like the 'quanta' previously referred to. Neither of these revolutionary developments contradicts, but only supplements, the 'classical' treatment by which radiation is a system of waves and matter is a system of particles. In fact we arrive at the dualism of regarding the one half of the physical world, the material, as in some of its aspects a wave phenomenon and in others a community of particles; in the other half, the non-material world of radiation including light and radio, the energy is carried as if by waves, but in some of its interactions with matter behaves as if localized into quasi-particles or quanta.

It is to be noticed that both the wave and the stream of particles are notions derived from large-scale observation of perceptible things which exemplify Newtonian mechanics, whereas electrons and electromagnetic waves are not objects of direct perception. Their epistemological status will be discussed later, but we can realize at once that it is not the isolated fact of obedience of electrons to 'wave' laws nor of radiation to 'particle' laws which points the inadequacy of mechanism as a truthful explanation of physics,

Each is a legitimate mechanism, but taken together they cancel out our old-fashioned confidence. The constituents of matter and the facts of radiation both vacillate disconcertingly between the two behaviours of wave and particle, each of which has a mechanical meaning but a meaning each exclusive of the other. For an electron to 'be' a wave and also to 'be' a particle deprives either description of that decisiveness which was the essence of passing from hypothesis to law and 'knowing the truth' in the intellectual security of our fathers.

The dilemma of the ether, which had to be a medium but possessed no physical properties, was a faint forewarning of the dilemma into which a belief in mechanism would plunge the modern electronic researcher. When forced by the wave aspect of the electron to ask 'What quantity is it that vibrates in this wave-representation of matter?' the commonest answer has been 'The quantity is a probability of something unknown'. Eddington's brilliant writings have well pictured this agnosticism, though I shall not confess to any agreement with the philosophical position he adopts as sequel. But the situation leaves little of the Victorian confidence that under modern analysis we 'know what we mean' by 'mechanics of material bodies in space'.

Properties of space, such as 'seat of vibration of electrical quantities in radiation' and finally 'seat of vibration of whatever quantities give rise to matter', have thus ended the older distinction of emptiness compared with Light or with 'things'. The explanation of gravitation by curvature of space in Relativity will similarly call for assessment later. But it is worth noticing, as follows, an incongruity in the notion of Time which would also accompany a mechanical interpretation of atomic physics.

From 1913 onwards it was found possible to account quantitatively for many of the facts of emission and absorption of radiation, if we followed Niels Bohr in picturing the tiny 'solar system' of electrons in their orbits around a nucleus within each atom as stabilized in a way not accountable in Newtonian mechanics. A 'classical' or strictly mechanical electron in its orbit would not remain stable if it gave out energy by radiating; so we had the impossible situation that a genuinely mechanical atom would either mean a permanently invisible universe of matter, or a universe which had no chemical stability since no atomic species could main-

tain its electronic orbits for a fraction of a second through radiation losses. Bohr's defiance of classical mechanism solved the impasse by postulating that the electrons radiate not while circulating in their orbits but only while jumping from one orbit to another; his list of possible orbits for these jumps had to be governed by a 'quantum' restriction such as I have already described, permitting only those of certain discrete energy content instead of the set with continuously variable energy content that any classical mechanism would require. Though lacking any 'cause' intelligible to mechanics, this scheme was a remarkable success in that it predicted with very great accuracy the exact energy of spectral lines emitted by Hydrogen, Helium, and the other simple atomic species; it even explained in terms of relative masses of electron and nucleus, and of the variation of mass with speed, some of the most minute deviations from pattern in laboratory and stellar spectra.

Since 1925 the theory has not been so blatant a superposition of non-mechanical upon mechanical concepts, but instead a more systematic reconstruction whose basis segregates the quantum restriction; only in Heisenberg's and Dirac's treatments is any homogeneity attained, by recognizing that a mechanical sequence is not to be pursued as a fetish when a useful but unlabelled group of symbols brings the experimentally correct solution of the equations. Heisenberg has a limitation to the size of mechanically arguable quantities which I shall discuss later, but the most significant break with mechanism seems to me to have occurred early in Bohr's most successful invention, the electron which radiated only BETWEEN leaving one orbit and lodging in another. This electron appeared to have foreknowledge of its destination, since the numerical frequency radiated depended upon the final orbit as much as upon the initial orbit. Since these frequencies are among the most precisely measurable of all physical quantities, to an accuracy of one part in many millions, we have to associate with the most rigorous of our experimental disciplines a period of scientific history in which we learnt that we could thus give no quantitative meaning to temporal relations below a certain magnitude. Until Dirac's work this was a situation no one was able to face, unwilling after three centuries to imagine a Nature not mechanically intelligible.

(IV) INADEQUACIES OF THE NOTION OF CAUSE

So many topics under headings of Causality, Causation, Law that similar causes produce similar effects, etc., have been exhaustively treated by philosophers and scientists, that drastic selection must be made in any essay claiming originality to-day and also claiming strict relevance to our present preoccupation with the meaning of scientific truth. For instance, I shall not trespass into the metaphysical discussions of Cause which have flourished inconclusively since Hume, and which are entangled with the formally insoluble problem of Free-Will which we all solve in practice for ourselves: in particular, no time will be wasted here over the preposterous fancies which recently utilized a spurious misinterpretation of Heisenberg's physics to ascribe a species of Free-Will to electrons. Further, I shall accept as indisputable without more argument some facts already discussed here. These may be summarized as follows: from Section (I), a confidence that similar experimental conditions will be accompanied by reproducible observation is an empirical 'uniformity' without which research would be chaotic. From Section (II), causal laws, in which accounts of a 'force' supplant mere description of motion, have been a valuable characteristic of modern science, only demanding question when certain extreme magnitudes are reached. From Section (III), quantum restrictions in atomic physics were successfully introduced regardless of entire lack of any rational 'cause' for them.

The present problem is therefore of understanding how to recognize adequately the services which these notions of cause have rendered and will still render, and yet to recognize where and why the limitations to such services arise, so as not to delay progress by the obstructiveness which first greeted Bohr's 'uncaused' quantum orbits.

All views of scientific truthfulness, whether based on causality, or on mechanical treatment of motion, or on the newer emphasis upon 'structural pattern' which I shall develop later, would agree that what is significant is the ASSOCIATION of experiences. Typically, if n occurrences are observed, we seek the grounds on which an $(n + 1)^{th}$ occurrence may with confidence be expected similar to or differing from them in some known manner.

Such occurrences taken individually can satisfy no one but the

'collector', so their grouping has been a main aim throughout scientific history. A first serious attempt at such grouping was the quantitative association of experiences in terms of the Newtonian rules. Force was defined by associating change of motion with the experience of inertia, the latter giving rise to the notion of mass and of its calculable analogue in rotational motion. Forces are then assessable from known responses of a known inertia, though often it is not clear in a physical argument which is the datum and which is the sought because much finding is inferential and not direct. Carried into Electricity, the mathematical methods elaborated by later workers for a Newtonian gravitation were very valuable in mapping the fields of force or the specially utilizable regions around any electrical apparatus which was regarded as ultimately reducible to charges in motion. All the vast technological ramifications of to-day require no addition in principle to the notion of fields of force and moving charges; they differ mainly in size from the mechanical extrapolation to objects inaccessible in sense-perception such as the undissociated molecules of a gas, and the extrapolation also to near astronomical bodies.

A simple summary of such procedure was to say that scientific laws formulate a relation between cause and effect, and that the business of the scientist is concluded when and only when any causal chain is completed.

Disastrous though this interpretation has sometimes become, it is not unreasonable when typified in the crudest sense-perception; increase of deliberately applied muscular effort, or increase in chosen arm of a lever, appears to 'cause' a lift of increasing mass of material. Extension into extremes of size is often untroubled, for example when we double the strength of an electric field and observe corresponding increase in frequency of X-rays associated with the increased acceleration of driven electrons whose size is reckoned in millionths of a millionth of a centimetre. Nor does it shock more than a sense of magnitude, to say that a stellar explosion, so distant that light has taken centuries to reach us, has a 'causal' relation to an image on to-day's photographic plate.

So it is not MERE reduction or expansion in scale that vitiates the causal sequence. But other more subtle features accompany some of the extension of the classical argument of causal mechanism to the very small and very large, and closer analysis of these may bring

doubt as to whether any general Law of Causality is so universally applicable as to stand for a foundation of scientific knowledge of truth. I shall outline some of these now, as more relevant to the inquiry than the very ambiguous LOGICAL status whereby Causality has proved deducible from no wider principle and is only of service when contributing to that Induction by which alone it could be established.

(*a*) *Restricted causal lines in early Relativity*

Temporal order here becomes important, as it has intrinsic relevance to some definitions of Cause in the larger phenomena of Nature. Our crudest example of causality had a reversible aspect, since increased muscular effort might be regarded as either cause or effect of the lifted load. But in more precise analysis, the earlier of any two events in certain time sequences came to be regarded as the 'cause' and the later as the 'effect'. It is therefore significant for defining Causality that the first Relativity statements of Einstein in 1905 drew a precise restriction round the meanings of 'earlier and later', previously accepted uncritically as having some absolute significance. 'Events', the individuals out of which the description of the universe of experience is built up, are separated by 'intervals' which themselves have spatial and temporal components, since any occurrence is defined by its epoch as well as by its locality. For any single interval the question of whether it is purely temporal or purely spatial or a mixture of temporal and spatial no longer has a unique answer; Einstein showed why the validity of the possible answers was accurately set forth in the Lorentz equations, which express how observers at their own different speeds partition differently any interval into spatial and temporal components. OBSERVED intervals are what concerns physics, and Minkowski's diagram classifies pictorially the possible lines connecting events as capable or incapable of a causal interpretation, the observers' velocities superposing an infinitely varying set of frameworks able in certain cases to turn a relationship of succession into a relationship of simultaneity. Such 'relativity' replacing any 'absolute' character of observable temporal quantities must carry with it a relativity of many causal relationships, when a succession of the 'effect' after its cause for one observer becomes a simultaneity for another observer.

(b) Ambiguous properties of space as causal in general Relativity

If the Relativity of 1905, dealing solely with unaccelerated motion of observers, gave a restricted and precisely controlled meaning to the notion 'later than, therefore possibly caused by', the more general theory of 1915 onwards introduces quite another modification to established meanings of causation. It happened that gravitational force, by many physicists regarded as a causal agent, was found to be representable in terms of a property of the space-time framework of events itself. This property, which provided a notion equivalent to and conveniently replacing the familiar forces of Nature, had some analogy to the property familiar as 'curvature' when we meet it as a character of lines and surfaces; in the geometry of Relativity, however, it is not defined through the sense-perceived property of that name, but through manipulation of the terms in an equation. The equation is a far more general one than its simpler analogue in the lines and surfaces of perceptual experience, and only the brilliance of Eddington's imagery has reconciled the devotee of 'perceptually based science' to the mathematically rational notion of curved space.

But once the equations involving space-curvature were successful in REPRESENTING the behaviour of gravitating bodies, this geometrical property assumed in the minds of many the causal character that had somewhat uncritically been accorded to the forces which it superseded.

This may legitimately be taken as an example, added to those of Section (III), that spatial and other physical 'categories' have lost the independence which in classical mechanism was essential: it introduces an even more disconcerting questioning for the future scrutiny of what can truly constitute a 'causal agent' in any truthful statement about the world. When we ask 'how does space-curvature CAUSE the motion of gravitating bodies?' we healthily admit that the borderline has worn thin between the older concepts of 'caused by' and on the other hand 'capable of representation in an equation': other developments than relativity may possibly converge upon a future decision to omit the 'causal' from the most important of physical propositions. Meanwhile Milne's novel system of relativity (1935 onwards), in which inertia as well as gravitation for any test particle is a property determined by the entire remaining universe, will need to face the merging of the causal

into the symbolic type of descriptiveness, if it is to avoid the ambiguity into which De Sitter plunged the relativity of Einstein by introducing negative and positive curvatures of space. A critical introduction to the unreliability of space-curvature I have developed in an earlier book from the point of view of the meanings of physical Time.

(*c*) *Inaccessible causes in statistical physics.*

This introduces the most common apparent loss of causal reasoning, but it is actually the most understandable and superficial of losses. This is the seeming failure of the causal sequence in all branches of science where assemblages of large numbers of individuals are dealt with: it is a failure to predict effects from causes, but a failure in practice rather than in principle. Even when it was strictly held that the essence of scientific reasoning was to utilize for prediction a relation between cause and effect, it was already recognized that what can be very precisely known about the AVERAGE properties and behaviour of the assemblage does not always afford any information at all about any one of the individual members of that assemblage. Observation and experiment can establish regular data for the individual when he can be isolated on a detectable scale of magnitude; it can also establish regular and precise data about what the average member does, even if the individual is not accessible, so long as there are sufficient numbers to be statistically treated. Many 'laws' in gas kinetics and thermodynamics, of the highest importance, deal with the average and ignore the individual: for instance a gas at a given temperature may be precisely known to have a given fraction of its molecules moving with a given fraction of the most probable velocity, whereas no one ever claimed to predict the actual speed of any particular molecule in that gas. Similarly a statistician might quite correctly estimate the fraction of a large population which will die in a given year, without being able to make any prediction whatever as to the fate of a particular person among them.

The abandonment of the inference from antecedent to consequent in the causal manner, is here the lack of the antecedent data for the individual when the whole history of his community is nevertheless known. If the recent history of a single molecule

could be supposed written down, no one doubted that consequent conclusion as to its immediate future could be rigorously drawn. Physicists merely blamed the inconvenient wave-length of radiation which would be needed to fix the position and velocity of the inaccessible particle. A more radical breakdown of causal sequence is that associated with Heisenberg, as follows.

(*d*) *Intrinsic impossibility of causal definition in atomic physics.*

This is the most drastic of the criticisms to which the conventional ideal of science as sequence from cause to effect has been subjected. It has been called the Principle of Indeterminacy, but would be better called a 'numerical latitude of uncertainty in formulating the data required for causal prediction'.

In classical mechanics a future progress is predictable if a body's VELOCITY AT A KNOWN POSITION can be stated. A co-ordinate of displacement and a co-ordinate of momentum are both required. Heisenberg pointed out that below a certain magnitude these quantities are not merely subject to the inaccessibility they would have for the case of gas molecules, namely that we cannot use short enough wave-lengths in the radiation by which they could be seen; that in this case of the far smaller electron these quantities could not even be physically defined. A PHYSICAL quantity must be essentially something existing independently of the observer: this is true throughout physics though debatable enough in metaphysics. The ultimate connection between observer and observed is in principle a locating of the latter by the pattern of the radiation he scatters. For all objects whose size is large compared with the wave-length of the 'light' or other available radiation linking observer with observed, this locating can be achieved without ALTERING the momentum co-ordinate or any other specification in the physical description of the object. But the smaller the object, the more the process of radiation scattering modifies the very quantity we set out to observe. In fact, of the pair of required data for mechanical prediction, position and velocity, the closer the one is approached as a definable quantity the more elusive the other becomes in the growing latitude it imposes upon our error of measurement. In the end the process of 'knowing' destroys the 'known', and no fantastically imaginable extension of wave-lengths can bring nearer the intrinsically inaccessible knowledge. The healthy

tendency, initiated by Einstein, to omit from the physical dictionary all notions inaccessible even to hypothetical observation and in fact involving contradiction in terms, relegates causal laws below Heisenberg's 'quantum' limit to the limbo where the fictitious ether had already been sent.

This last limitation upon the possibility of tracing effect from cause, imposed by the principle that an act of measurement must not alter the magnitude to be measured, might well be ascribed to some 'Principle of Objectivity': by this would be recognized a requirement which I shall discuss in another connection later, that physical science is concerned solely with a Nature which must be abstracted as external to the Naturalist and strictly uninterfered with in all the processes of observing. The magnitudes of the physical quantities must be as independent of any reaction to the physicist, as his own opinions about them must be independent of his personal preference or bias.

(V) CURRENT CONTROVERSY AS TO THE SHARE OF RATIONAL AND EMPIRICAL METHODS IN SCIENTIFIC ARGUMENT

The detailed treatment of successes and inadequacies of causal mechanisms (II, III, IV), provides a commentary upon the approaches to knowledge of scientific truth via hypothesis and law (I), which may now facilitate some wider exploration.

Doubts raised by the weakness shown in causal mechanics are not necessarily doubts as to the inductive procedure and its utility, but as to its exclusiveness: historical accident simply gave to traditional scientific method its most unquestioned successes, before the advent of deeper research from which the present difficulties could arise. The years in which those doubts have grown, however, are culminating to-day in a time of controversial claim and counter claim as to whether after centuries of inductive exploration there may not be room for a novel use of deductive reasoning of a kind less primitive than the crude syllogism mentioned in section (I).

Reaction to such suggestion has been very sharp from those whom historical sense has led to prize the 'generalization from experiment' which served scientific truth from the seventeenth to

earliest twentieth century. In particular, Professor Dingle has vigorously attacked mathematicians whose researches in Relativity have led them to unorthodox views of Knowledge and its scrutiny or Epistemology, and who are therefore suspected of 'practising what is not physics'. The most obvious targets are Eddington and Milne, against whom lies the indictment of relapsing into pre-modern Aristotelianism and despising experimental approach to truth while expecting to infer laws without the appeal to experience which was the guarantee of the modern methodology. One of the greatest of mathematical physicists, Max Born, has published (1943) an excellent account of the indispensable character of experiment, and has been quoted as if supporting the attack on Eddington and Milne.

In the view which I have here been developing, the situation emerges as follows. In calm moments it will be agreed by all sides that there is no such thing as a purely inductive or a purely deductive Natural science. Rational deduction from more general propositions, and the empirical build-up of general from the more particular, are both necessary; but we do well to recognize that at different stages of a science the one method or the other may tend to be temporarily the more useful. The utilization of deduction most widely accepted as 'respectable' has been that whereby a general proposition inductively established on a basis of probability is tested in application to some new experiment. The deductive form is then hypothetical: 'If the general proposition which we think we have discovered is true, then if such and such experiment involves explicitly or implicitly such and such quantities from that general proposition, the result of the experiment is predictable and means so and so.'

It may possibly contribute some clarification to the current controversy, if we compare the kinds of general proposition which serve as Major Premiss on these occasions, firstly in classical physics of the highest respectability, and then in the revolutionary intellectual adventuring of Eddington and Milne. Vague accusations may at least be reduced to the exhibition of some specific stage at which their deduction differs from that employed by the most empirical in scientific history.

(a) The classical inferential sequence may be typified by a piece of atomic theory immediately preceding Bohr's introduction of

'quanta', which we may summarize: 'If we know that there are causes so universal that their mechanical effects are beyond doubt, and if an inverse square attraction and the radial forces of circular motion are examples of such cause, then to the adopted model of electron and nucleus with an orbit governed by electrostatic and rotational forces the causal mechanism and stability laws of elementary experiment will be applicable, and the loss and gain of energy will be calculable.' After a chain of such hypothetical inferences a stage is reached where the energy calculations can be compared with the facts of spectrum photography: I have outlined in section (III) the way in which Bohr dealt with the invalidity of this chain, which was formally correct but materially false.

(b) A type of argument introduced by Eddington may be taken from his researches on the unification of quantum and relativity theory; I hope it is not misleading to paraphrase and summarize as follows: 'If the most general ways of arranging the association of any entities or operations into groups represent a fundamental mode of reaction between mind and its environment, and if certain symbols interesting to physicists involve operations thus relatable into groups, then application of the standard calculus of mathematical groups to such symbols may be expected to yield prediction of properties tested by physical experiment (such as the "fine-structure constant" and the mass-ratio of proton to electron).' The intermediate steps are of course far more complex than shown in this simplified scheme, but I think that the essence of the logic is all there.

(c) A sequence characteristic of Milne may similarly be paraphrased. 'If the need for observers to correlate their observation of a time order into a unified system of laws is not merely a necessary but also a sufficient condition for the most basic of physical knowledge to be discoverable, and if light signals with an agreed constant resembling a velocity can be adjusted to build such a correlation, then the forms required by the process of correlation may contain implicit in themselves some of the regularities already met in observation. These regularities include the Lorentz transformation of Relativity and many properties of matter, inertial, gravitational, and electrical.'

What are the features absent from the kind of argument (a) but

present in (b) or (c) and regarded askance by some empirical physicists?

Firstly, the propositions from which the traditionally accepted argument begins as equivalent to major and minor premisses are themselves PHYSICAL propositions: this is taken to mean that their terms concern the 'things' which physicists have from time to time postulated as underlying sense perception, such as forces, atoms, electromagnetic fields. A physical deduction must come from a physical law. On the other hand both Eddington and Milne trace the sequence back to some EPISTEMOLOGICAL premiss, or some proposition concerning what we are to mean by 'knowledge'. Eddington starts from the fact that our minds are capable of certain restricted ways of assembling data into quantitative structure, and Milne starts from the fact that individual perception orders events into time sequences and that knowledge becomes possible if these time sequences can be shown to be connected. I shall later try to relate these kinds of major premiss to a demand that knowledge shall be 'communicable' if it is to be true and coherent.

This deducing of physical propositions from epistemological premisses, as occurred with Milne's version of inertial and gravitational laws, has been regarded by many as improper; it is undoubtedly a revolutionary step for those who regard physics as a closed system in which only the physical can give birth to the physical unless 'physical' becomes redefined as 'knowable' or 'intelligible'. The impropriety might have to be regarded with less of a shock if we recollected that the Law of Causality—major premiss to so much science of the past—is scarcely 'physical' except in this novel sense.

The second and also offensive novelty appears to be that the laws deduced from epistemological premisses are not so much extensions but rediscoveries of theorems already known empirically. If an entirely new law is inferred *a priori* it is not treated seriously until experiment checks it, but once thus verified it would certainly be greeted with enthusiasm and not with the complaint that it is an insult to science: that complaint has nevertheless greeted the proof that a well-known law originally empirical can now be deduced from epistemological grounds.

There seems a psychological aversion to 'going behind the induction already established'; is it possible that the most damning

indictment of Milne and Eddington comes from a fear that future physics might have to take account of the physicist's mind?

But such an eventuality, perhaps more agreeable to Eddington's general standpoint than to Milne's and highly relevant to important questions in philosophy, would have no relevance whatever towards the correctness or incorrectness of the physical laws epistemologically deduced. The latter alternatives, as Eddington and Milne would be the first to agree and as our abbreviated type-arguments (b) and (c) showed, must be settled entirely by observation and experiment. It is a business of theory to predict something capable of test, and a business of the experimental physicist to say the final word when carrying out that test for deciding which of many possible worlds is nearest to the world of experience. If so, there seems no warrant beyond emotional prejudice to support the experimenter in complaining that the theory contains 'non physical' premisses—unless he has a metaphysical axe to grind depending on some philosophy to which he feels bound but which he is not prepared to argue on philosophical grounds.

I have already in (I) called attention to the fact that a physicist's mental attitude may include more than the detailed steps of his formal argument: if the protagonists in the controversy over the 'new rationalism', introducing wasteful acrimony into the pages of 'Nature' and 'Philosophy' and other publications to-day, could each believe that the other is not trying to 'take down the conceit' of theory or of the empirical method, there would be more hope of our seeing through to a balance of where both deductive and inductive methods are going to be essential in the next stages of physics.

That well-known laws in physics, first discovered by the inductive chain of hypothesis employing causal mechanism, can subsequently be recovered in more intelligible shape by deduction from the laws of reasoning itself, is a remarkable contemporary accompaniment to the exposing of failures in the causal mechanism such as revealed by relativity and quantum atomic research. The oversimplified tradition of dividing scientific approach to truth as Formal Deductive mathematics and Empirical Inductive natural science, from which I set out in (I), is clearly now inadequate to the meaning of truthful argument. Both contributions to 'natural knowledge' may more satisfactorily be seen as different sides of a common scheme of thought, if we notice in the next Section (VI)

how recent pure logic has been recognizing a corresponding unification across its traditional distinctions.

(VI) COMMENT FROM MODERN LOGIC; PROBLEMATIC AND DEMONSTRATIVE INFERENCES, COVERING INDUCTIVE AND DEDUCTIVE METHODS

Practising scientists and general readers, led to regard 'logic' as merely the set of formal rules for avoiding argumental fallacy which have not altered noticeably in many centuries, are not always willing to recognize that it is a subject whose significance for science has developed enormously through its advances in the twentieth century. But quite new possibilities of analysing a situation in the natural sciences may, with care, be shown to emerge from the researches of Bertrand Russell, Frege, Peano, Whitehead, W. E. Johnson, J. M. Keynes, C. D. Broad, Wittgenstein, F. P. Ramsey, and others, not to mention the Oxford logicians much of whose work is inseparable from an idealist metaphysics not very appealing to many scientists. Some of these possibilities must now be noticed, before we turn from the previous criticisms arisen within physics to ask what is to survive out of scientific method, in assigning meanings to truth.

There seem to me to be three main lines of recent research in logic of importance to the present problem because of the light they can throw upon the validity of inference. (a) Transformation of the old rules of classification and deductive procedure into a general rational analysis of the meanings of Form, Order, Relation, Variable, Propositional Function, Implication, the calculus of Classes and the calculus of Propositions, has put mathematics and some aspects of natural science into an intelligible place among intellectual activities. (b) The traditional severance between deductive seeking of 'certainty' in the rational sciences of mathematics and inductive exploration of the 'unprovable but likely and useful' in the empirical sciences of Nature, can now be seen to be misleading, as it blurs more important distinctions of probability which decide the application of both deductive and inductive principles. (c) There must consequently be new meaning, compared with that accepted in a previous generation, to the notion

of 'conditional or hypothetical statement' as an approach towards truth.

The developments which I have called (a) will call for some mention in Chapter 4. The remainder of the present Section attempts an introduction to (b). This may make it possible in Chapter 2 to assess some of the modifications already called for by modern physics; following (c), the old use of hypothesis in induction may be replaceable by new recognition of just where interpenetrating stages of scientific argument can be analysed into the rigorous and the problematic.

The most essential modern antithesis is not between Deduction and Induction but between Demonstrative inference and Problematic inference. Both interpenetrate disconcertingly throughout physics. But among demonstrative inferences there ARE some types of induction or the reaching of general conclusions by means of particular instances; the situation is analysed most exhaustively in the treatise of W. E. Johnson and some classical papers by C. D. Broad on demonstrative induction. Until this was recognized, science had vacillated between following Bacon's respect for analogies and his distrust of deductive proof in his enthusiasm for experiment, as Keynes has discussed in his *Probability*, and on the other hand Mill's attempt to define induction as 'proving general propositions' in regions where proof is actually beyond reach. Mill had regarded Causal laws as established with rigorous certainty, and his influence colours even to-day the working scientist who has ignored recent logic.

W. E. Johnson classifies as follows the ways of seeking truthful argument.

I. DEMONSTRATIVE INFERENCE

(*1*) *Deduction through an Applicative Principle*

Typically, the proposition 'All S is P' warrants the proposition 'the given S is P'. The argument passes from 'every' to 'any particular instance'.

(*2*) *Deduction through an Implicative Principle*

Typically a compound proposition of form 'x' and 'x implies y' warrants the inference 'y'.

The traditional syllogism, or inference from Major Premiss via Minor Premiss to a conclusion less general than the major, must utilize both of the Applicative and Implicative principles; but the principles themselves require universal premisses only obtainable through Induction.

(3) *Intuitive induction through Counter-Applicative Principle*

There are occasions on which we see that what is true of a given instance is true of any other instance. We see the general in our examination of the particular, and the argument passes from 'this' to 'any' and from 'any' to 'every'.

(4) *Intuitive induction through Counter-Implicative Principle*

There are occasions on which, having made a valid inference, we see that its validity is due to a certain form of relation between the premisses and conclusion, and we gain generality by abstracting the form for other use.

Restrictions are of course necessary, but are not our concern in this classification. Intuitive inductions provide the basic grounds for mathematics and for logic itself.

(5) *Summary induction*

This provides conclusions, often based on enumerations which apply only to the instances of the premisses, but also sometimes applicable to infinite classes; this type of induction constitutes the basis of much geometrical argument.

(6) *Demonstrative inductions of exploratory experiment*

This covers types reducible to hypothetical syllogisms in which an 'instantial' premiss from a particular instance observed is used towards a universal conclusion. Mill's famous methods of experimental inquiry can be usefully reduced to this demonstrative form with the great advantage of showing where certainty of truth fails. His traditional 'method of agreement', 'method of difference', 'method of concomitant variation', can all be summed up in the advice upon which all experimenters act: 'Vary only one factor at a time and so isolate the relevant from the irrelevant circumstances under which a given phenomenon becomes observable.' W. E. Johnson reconstructs these 'methods' into 'Figures' rigorously

definable as specifications of a composite premiss and generalizations of an instantial premiss; the major premiss for any example of each Figure is of the type 'The variations of the phenomenon P depend ONLY upon variations in the characters A, B, C, D,——.' The minor premiss involves instances in which one or another of A, B, etc., is varied. The conclusion asserts something wider than was stated in any of the instances, and concerns cases not yet observable, so that it is a genuine induction.

A case of immediate universalization, so crude as to be shorn of the usual complexities in the major premiss but yet exhibiting the form, might be: 'Every specimen of argon has the same atomic weight, this specimen has 39·9, therefore every specimen has 39·9'; the form is correct but the validity of the first premiss is vitiated by the subsequent discovery that the 39·9 represents a mixture of two isotopes of which in ordinary specimens the '40' is more abundant than the '36'. Other simple examples might be that in considering the volume v of a specific gas g at pressure p and temperature t, observation that change from t to t_1 entails change from v to v_1 if p is unaltered, can warrant inference that change t to t_2 will entail change v to v_2 (Figure of Difference). Again, from instances where under constancy of relevant circumstances the rate of gravitational fall is the same for different masses, an acceleration independent of mass is inferred (Figure of Agreement).

The essential point is that the conclusion is both a generalization and yet follows of necessity from the premisses—the inference is both inductive and demonstrative—but it is only a PROBABLE conclusion because somewhere there is a premiss which is only probable. It is vital in giving meaning to 'truth' in the sciences, to recognize where modern logic thus segregates the factor of uncertainty; just as in the deductive inferences (*1*) and (*2*) the forms are rigorous though the Applicative and Implicative principles are inductively established, whereas the conclusion is limited to not exceeding in probability the degree to which the more universal of the premisses is established.

II. PROBLEMATIC INFERENCE

Until recently this topic contained the whole of what was considered the concern of natural science. Both in 'pure generaliza-

tions' and 'statistical generalizations' the stage at which the 'uncertainty' enters is not so subtly concealed as in the Demonstrative inferences of science. The conclusions can be asserted with increasing probability the larger the number of instances assembled in support. But this probability, though a fraction which may be relatively great and therefore of importance provisionally to science, never reaches unity or can be called a certainty. Not very successful attempts have often been made to reduce all such reasoning to a syllogistic form, by invoking as supreme major premiss a supposed Law of Causality, and I have in earlier pages indicated the weakness of such a basis. The only successful bridge between Demonstrative and Problematic induction of which I am aware is W. E. Johnson's 'functional extension of demonstrative induction' which introduces the mathematical calculus of Probabilities essential to assessing scientific exploration, as in Keynes's treatise on Probability.

The above classification of inferences seems to me to shift somewhat the grounds on which the most striking ventures of recent physics can legitimately be judged, as follows.

To object against Eddington and Milne that natural laws cannot be discovered by deduction but only by induction, is to ignore the interpenetration of rigidity in inference with uncertainty in premisses, which I have quoted as a feature of modern logic affecting both deductive and inductive chains of argument. The fallacy of the pre-Bohr argument on electron orbits in (V) and of the pre-isotopic argument on atomic weight in (VI) indicate where instead the legitimate line of attack upon Eddington and Milne must lie. The Law of Causality, beloved of Mill and the Victorians, has forfeited our confidence, but it becomes all the more essential that we should not allow to remain hidden any other major premiss which decides the degree of uncertainty in the rigid deductive systems of such mathematical physicists.

It may now be realized why I placed at the head of imagined arguments in (V) a major premiss hypothetical or conditional in form. The perfectly rigorous deductive chain of the Rationalist is as liable but not more liable to fail through weak probability of a controlling premiss as is the looser inductive chain of the Empiricist. It is a fact that the DEMONSTRATIVE steps in relativity, quantum physics, and cosmology, often accused of being 'not physical'

by experimenters, are seldom attacked, nor are the final laws controvertible if they are rediscoveries of well-known observational facts. I have also pointed out (V) that the objection to a 'non-physical' premiss must be made on philosophical and not physical grounds. But there does remain the uncertainty of the major premiss which asserts some property concerning the nature of reasoning and not the nature of the external world: future scrutiny must be directed at the hidden premiss 'that there is a particular way in which Mind can apprehend Order', whether it be Eddington's 'group patterns' or Milne's 'temporal sequences'. For we do not yet know whether either of these premisses is true or whether alternatives might equally be true; the authors assume them true and their adversaries assume they are either untrue or are trivial. I have tried to show that they are important, and that the revelation of their status by modern logic suggests we shall not know fully what physics means until we find whether they are true or not.

Chapter 2

WHAT SURVIVES OF SCIENTIFIC METHOD?

1

The critique of scientific method evolved in Chapter 1 supplies evidence for the following statements.

(a) Modern science had matured by utilizing the notion of 'forces causing changes in motion', instead of being contented with the narrower ideal of mere geometrical description of bodies in motion. The Newtonian scheme based thereon had provided a means of striking progress via Hypothesis, Experiment, Natural Law, towards a mechanical explanation of many facts in astronomy, the gas laws, electric conduction, electromagnetic wave theory of light, etc., until the present century. (Sections I, II.)

(b) But progress through the use of these mechanical concepts comes to a disconcerting halt when a medium for the electromagnetic waves is demanded, when ground for quantum selection in atomic explanation is demanded, when questions are asked as to how the time of radiation and time of occupancy of an atomic orbit are to be identified or separated, and when some behaviour of electrons is expressed as a mechanism of particles and some as a mechanism of waves. (Section III.)

(c) The ideal of tracing events as effects of causes is now restricted by the facts exhibited in the earliest Relativity, that the existence of causal lines connecting events is conditioned by the velocity of observers. The notion of Cause also loses its original lucidity when forces are replaced by space-curvature as 'agent' in later Relativity. Prediction of effect from cause also fails in statistical physics where the data for individual velocity and location become inaccessible, and more fundamentally it fails in quantum theory where below a magnitude limit the data cease to be definable in physical terms. (Section IV.)

(d) These limitations to confidence in the utility of causal laws remove much of the prestige of a Law of Causality as major premiss for inductive logic. The modern analysis of demonstrative and problematic inference, showing where the rigour and the uncertainty enter into both deductive and inductive chains of scientific argument, removes some of the objection brought by empiricists against 'deduction of physical law', and indicates that it is rather in their hidden assumption of a premiss concerning the nature of reasoning that explorers such as Eddington and Milne are to be judged. (Sections V, VI.)

2

The following most general requirements of scientific method seem to me to survive the above criticisms, either unmodified from the traditional scheme which was outlined in (I) or with modifications or novel features which will here be pointed out.

(*a*) *Measurement*

Physics depends first of all upon measurement, which may be more precise or less precise in various branches of inquiry. Other sciences involve further requirements peculiar to themselves, but to greater or lesser degree they also utilize measurement, for example in the physical chemistry of physiological processes such as nutrition and poisoning through the semi-permeable walls of the living cell. The reason why little progress in physics can be made without measurement, and why even biological and psychological sciences tend to import measurement when the nature of the observations permit, is that only concerning the QUANTITATIVE can statements be made on which there is any decision as to whether two scientists agree or disagree. Contrast with physics, for example, the impossibility of agreement between two art critics, or between two followers of different religions, because their judgments, although very important, are essentially QUALITATIVE and not expressible in terms of verifiable measurement.

(*b*) *Abstraction*

It is open to any laboratory to make an infinite variety of measurements, but only a few of these are of scientific interest. Those

few are the measurements from which circumstances that were solely due to local or individual control can be eliminated. This elimination of the irrelevant, so as to preserve and analyse the relevant, is a very widely applicable requirement: it decides the wise research director's selection of which experiments to sanction, and it decides the eventual mathematical form of scientific theory. For instance it could be said to be the prime impulse of all Relativity physics. It may even become a criterion of scientific 'truth', in the definition which I shall later propose. It includes the 'reduction and simplification' of all scientific data, and it is perhaps best described by the general statement that observation and experiment serve to ABSTRACT something from common experience. All scientists would, I think, agree with the term 'abstraction' as what they are seeking, but there is little further agreement if we persist in asking what is the 'something' which is to be abstracted from our measurements when the irrelevant has been correctly eliminated.

(*c*) *Transformations and invariance*

After the results of measurement have passed through stages of 'abstraction', such as their embodiment into equations or into lists of atomic weights or chemical structures or elastic moduli or optical and electrical constants or any other convenient headings into which might be grouped the more classifiable of properties, general propositions can be formulated from which inferences can be drawn. From these inferences, discriminatory experiments can be designed, for showing whether simpler or more intelligible rearrangements of the original measured data might have been selected.

Such inferences will not all be of the same logical type, and the interpenetration of deductive and inductive demonstration that I outlined in (VI) of Chapter I will lead broadly to FORMS as well as to QUANTITIES becoming available in the theories: these have to be compared with the results of the discriminatory experiments before we know whether the exploration hitherto has been on profitable lines.

Now the theoretical evaluation of QUANTITIES was familiar in the older logic of the sciences; for example the position and mass of the unseen planet Neptune, or the frequency of radiations from a

hitherto uninvestigated state of a gas inferred from its place in the periodic table, are impressive predictions capable of verification. But the theoretical evaluation of FORM fulfils a more modern and subtle need: perhaps a widespread instance is the identification of the 'wave' form when many kinds of equation are suitably juggled with. The importance of such technique has led to an enormous expansion of the physicist's interest in the conception of TRANSFORMATIONS. This mathematical term may perhaps be described in the following way. If some regularity in observed facts has been embodied into equations showing the dependence of one variable quantity upon alterations in another variable quantity, for instance velocity of fall related to height fallen, so that the one is a 'function' of the other, then the final goal of the process of 'abstracting' is that the regularity shall be 'invariant' during all ways of 'transforming' the original statement: it must be formulated so as to be independent of adventitious circumstance, and give a rule suited to all possible variety of observers. We are not interested in the speed at which bodies from a particular tower hit the ground, or even how speeds in falling would appear to observers ascending or descending by a lift meanwhile, but in a statement extracting an invariant law which can then be rewritten correctly transformed for each required occasion. Functional relationships of the maximum usefulness to science are therefore those exhibiting the quantities which are invariant under the widest transformations, and a set of measurements may be valuable or not according to the FORM which can be made from them. For example a turning point towards the discovery of the relativity of time and space was the recognition that Newtonian equations of mechanism do not exhibit the same invariances when the observer's velocity is taken into account, as do Maxwell's equations governing electromagnetic phenomena; the present era of physics might be said to date from Lorentz's discovery of the correct transformation for finding what laws are independent of uniformly moving observers.

3

The FORMS of scientific knowledge, in particular this emergence of invariance for the more important laws after discovering the widest transformations for the equations, are more nearly what

the physicist seeks to-day, in place of yesterday's aim of converting HYPOTHESES into LAWS OF NATURE. The implied modification in scientific method arises from the inadequacies which we had found in the arrangement of physics into mechanisms of cause and effect. For a physical hypothesis was nothing more than a tentative supposition as to the activity of model bodies, a supposition that underlying the perceived phenomena were unperceived bodies obeying the same mechanical laws as those which characterized the behaviour of gross matter moving in directly measurable paths. Up to a point these unperceived bodies do seem to act like miniature hard spheres, but only up to that point: the failure of such a 'model' for the electron and even the chemical, radioactive, and optical behaviour of atoms, sets a limit to this type of hypothesis. The alternative model of an electron represented by a wave is not in the same sense a completely mechanical hypothesis, as it is impossible to picture what vibrates and in what medium. The equations of wave form, however, with omission of any causal agency from their specification, do supply a very valuable pattern of symbols, in spite of the fact that these symbols lack any clue to provide the mechanist with a hypothesis as to 'what they are'. For the transformation properties of these equations show that we have abstracted something of more significance than any model piece of miniature matter; they enable predictions to be made as to electronic behaviour in optics, spectra, chemistry, and other studies of the properties of matter and radiation which had defied attempts to compose a law of Nature out of a selection of mechanical hypotheses. When instead scientific method becomes the abstracting of unlabelled regularities, we not only emancipate ourselves from hypotheses in the sense of pictured mechanical behaviour, but we also refrain from claiming to have reached the old-fashioned finality of 'law': we only congratulate the researcher that the transformations are progressively more comprehensive over all physical change, and that predictions are showing by experiment a probability tending towards unity.

This procedure is most adequately embodied if the relations between observable or transformable variables can be exhibited as some standard form of Differential Equation, i.e. if the RATE OF CHANGE of some quantity depends upon and is a known function of the rate of change of another. Static configurations of 'things'

are seldom of importance to physics, and our more vital interest is in their tendencies to alter, and the differential equations show what controls that alteration; the precise character of the 'flux' of any property tells more of its nature than any 'still picture'. This is one of the reasons why 'Time' is the most essential of physical variables, as I have emphasized in an earlier book.

4

For examples of the way that 'emergence of a form of relationship between variables to which we cannot give mechanical meaning' replaces the 'turning of hypothesis into law', consider the changed status of two very important physical concepts, the electron and the electromagnetic field. The electron was until recently understood through the notion of a model; first it was thought of as a tiny piece of matter, then as a wave pattern, both being conceptions familiar as obeying Newtonian laws. The former model was partially correct, in that any beam of electrons accelerated by an electric force can be bent by a magnetic force, and the degree of acceleration and of bending fits precisely a property of 'inertia' analogous to that of perceivable objects: it can be assessed as about 9×10^{-28} gram or about 1/1850 of the mass of the lightest atom Hydrogen. But the other model, of the wave, is also partially correct in that the 'wave-length' can be measured in diffraction patterns, as a function of the electron's speed, although we cannot unambiguously describe what it is that vibrates. The two conceptions, regarded as hypotheses as to what the electron 'is', are mutually incompatible. So we now more healthily recognize that what we seek is a regularity in the differential equations for predicting verifiable numerical relationships, not any knowledge that an electron is a minute mechanism extrapolated from gross perception. As a 'singularity in space carrying inertial properties but also a centre of diffractable waves' we know all that is necessary without making the hypothesis of a model.

'Electromagnetic field' is a concept which again has a history passing through and out of the age in which distinction between transient hypothesis and permanent law demanded a mechanical or causal model. We say the region around certain kinds of ma-

terials is a region of electric field or of magnetic field; these were originally defined by the mechanical forces felt by an imagined test-object, but it is useful to suppose that these fields exist in one particular way even in empty interstellar space. For the most striking of their characters is that when alternating together they constitute a combined vibrating system with the remarkable property that the 'regions of electromagnetic field' propagate themselves through space at a fixed speed of 186,000 miles per second. Such movement of alternating electric and magnetic fields seems to underlie the phenomena of Light, X-rays, Radio, Heat radiation, etc. But the older MECHANICAL or CAUSAL concept of an advancing wave strictly concerns the vibration of some material medium, such as air or water or metal, which could carry sound waves or earthquake waves. In the case of Light and other electromagnetic waves, the medium vanishes and IS only the emptiness of space between here and the sun or stars, and the mechanist's imagination of an 'ether' was a myth to satisfy the desire for a causal model to explain. So again model and hypothesis dissolve into a reality which is solely the regularity experimentally verified and deducible from the wave equation after combining Maxwell's differential equations of electric and magnetic field. It is a 'reality' very present to anyone experimenting with radio. These Maxwell equations obey the Lorentz transformation, indeed were the first regularity of Nature to do so. To be able to handle their properties of transformation is, in an important sense, to 'understand' them physically.

5

'Intelligibility' has thus become divorced from fictitious claims to 'know what thing underlies phenomena' in any sense of devising a causal model of mechanism and expecting it to be a picture reduced in size from perceptual experience. If the differential equations and the appropriate transformations provide predictions quantitatively checked in experiment, we have the degree of understanding which is desired for those aspects of Nature interesting to physics. The expectation of this modest but very rigorously exacting type of intelligibility might even serve as 'major premiss of scientific inference', which we left unformulated in discussing the status of inductive logic in (VI) of Chapter I. It is possible that

when we unconsciously build a chain of scientific inquiry upon some hidden assumption, in place of the old faith in universal Causality we rest instead upon the statement that 'Nature is intelligible'. If so, the physicist's special version of that intelligibility will be 'measurements can be rearranged into regularities, and abstractions from those regularities can be exhibited in logical and mathematical form following simple transformations'. Such a version would demand no blind faith in Newtonian or other causal laws, and might join physics to more general epistemology; for it identifies the intelligibility of Nature with 'every event can be analysed into a LIMITED number of independent elements'. The latter proposition is a 'principle of limited independent variation' such as Keynes considers to have been the foundation of all Bacon's and Mill's work. It rules out the mirages of pseudo-science. It is certainly implicit in the demonstrative inferential systems of W. E. Johnson's modern logic. It writes physics as a set of Functional dependences, with the proviso that the functions must be of few variables at a time.

It is this fundamental hope, that the infinite variety of natural facts can be simplified through the physicist's processes of abstraction into a manageable finite number of forms, that has given to recent science its striking preoccupation with the mathematical Theory of Groups. Until the last twenty years, few mathematicians and hardly any physicists had taken notice of this simple and beautiful but thought-provoking borderline between pure mathematics and logic. Eddington is the only writer with the audacity to expound it in delightful and readable language. The theory concerns not the grouping of quantities but of 'operations' both logical and quantitative, and of particular importance are the properties of grouping sets of Transformations. I have already explained why the analysis of Transformations is at the root of ascribing any meaning to Nature, because it settles how 'knowing' can become independent of the accident of individual circumstance—an epistemology which will be much referred to in later chapters.

6

I have intentionally kept the surviving and growing features of scientific method extremely general in this chapter: 'measure-

ment', 'abstraction', 'form', 'transformation', 'intelligibility', are less easy terms to grasp in imagination than the older 'hypothesis', 'law of nature', 'cause', 'mechanical model', of the previous generation of science. It is mainly for that reason that recent physics is considered difficult for the non-physicist to follow, and why I have laboured somewhat the distinctions which result from the post-relativity and post-quantum attitude. These distinctions are the necessary framework within which alone can be understood just what Heisenberg, Einstein, Dirac, Eddington, Milne, have been able to contribute towards a novel meaning to scientific truth. These contributions will now be considered in Chapter 3 and related to Russell's logic in Chapter 4, and a new simplification then attempted in Chapter 5.

Chapter 3

INCLUSION OF THE CHANGED METHODS OF PHYSICS INTO THEORIES IMPLYING NOVEL MEANINGS TO THE TRUTH OF SCIENTIFIC KNOWLEDGE

(I) HEISENBERG AND DIRAC AS ENFORCING AN ABSTRACT TREATMENT OF PHYSICAL QUANTITIES AND SYMBOLS

Since this essay is not an exposition of the results obtained in recent physics, except so much as is needed to follow a changing view of scientific truth, I shall not here attempt the impossible task of reducing to non-mathematical description the atomic aspects of Heisenberg's and Dirac's quantum theories. Nor need I try to compete with the numerous popular expositions of 'the new physics': those of Eddington and Jeans are the most brilliant though I would prefer to dissociate their exposition of the PHYSICS from the PHILOSOPHIES which they have sometimes felt it right to associate therewith. Sir Charles Darwin's *The New Conceptions of Matter* is not only readable but entirely free from infringement of philosophical neutrality, and ought to be read by everyone who wishes to know what physics is doing.

But some quite describable features of recent theory have vital bearing upon the stage which we have reached in the previous chapters; this stage was the discovery of the inadequacy of causal mechanical laws, and the survival of Measurement, Abstraction, Transformation, Invariance, and the concept of intelligibility and limited variability, as foundations upon which must be erected any view of truth in science. In particular, after demonstration that 'thing' in the sense of 'mechanical model' is no longer the physicist's aim, the further notions of 'observable', 'physical state', 'operator', 'matrix', 'probability amplitude', will be essential to grasp. These are notions not necessarily inaccessible to the non-

mathematical, with care on the part of reader and writer, and it is worth remembering that in the late 1920's they proved startlingly unfamiliar and distasteful to the older physicists, some of whom can still profit by the most elementary exposition however profound their previous mathematical experience. Indeed mathematical PREJUDICE can be a worse barrier than inexperience.

It is a remarkable comment on the abstract and symbolic interpretation which has to be placed on the quantities appearing in the Dirac and Heisenberg equations for atomic relationships, that the initial impulse in such workers came from recognizing in the current atomic theory a certain fundamental defect; the defect was that its principal quantities were unobservable and inherently unobservable. The theory then current was Bohr's treatment of electrons circulating in orbits around a nucleus in each atom. The orbits of the electrons were mental pictures, mechanical models, intellectual constructs derived from large-scale astronomy, and the only FACTS to be observed were the frequencies and intensities of light emitted when an electron leapt from one supposed orbit to another; these frequencies and intensities were measureable to great precision as spectral lines on a photographic plate, whereas paths of electrons and dimensions were only calculable. Since the mental picture of orbits required the intrusion of an uncaused and non-mechanical 'quantum restriction', as described above in Chapter I (III), the usefulness of the orbital picture as 'mechanical explanation' was lost. Heisenberg, facing this loss, and asking what is to be the essential requirement for a theory to fulfil, accepted as primary the need for formulating relationships capable of predicting observable facts. This need was for the first time in scientific history seen to be NOT necessarily identical with the need to devise a new model picturing mechanically an unobservable process.

The step following this decision was essentially that if optical frequencies are what is observed, a form must be adopted for expressing the most general arrangement of periodicities into patterns. For such a need, there existed already the method devised by Fourier in the early nineteenth century for analysing any frequencies of any physical system into harmonic components, and this was profitably taken over by the atomic theories which date from 1925. But these components, being in the atomic case asso-

ciated with pairs of atomic states, could be expressed as patterns or arrays of symbols each characterized by a pair of indices: in certain cases such an array is known as a MATRIX, of which a simple example might start from the infinitely extending pattern

$$\begin{array}{ccccc} q_{00} & q_{01} & q_{02} & q_{03} & \cdots\cdots \\ q_{10} & q_{11} & q_{12} & q_{13} & \cdots\cdots \\ q_{20} & q_{21} & q_{22} & q_{23} & \cdots\cdots \\ q_{30} & q_{31} & q_{32} & q_{33} & \cdots\cdots \end{array}$$

The general term q (n,m,) has a simple periodic relationship to a set of physically definable properties a(n,m,) which becomes thereby treatable as if it were an 'amplitude or extent of range of vibration'; but it can also be treated as if it measured a 'probability of an electron's leap from one orbit to another' or 'transition from n^{th} to m^{th} state'. It can also represent a known function of the intensity of light emitted and measureable.

These identifications gave the basis for a real use to the term 'probability amplitude', which became the quantity most valuable to calculate for predicting an experimental result in atomic physics. We do not have to assign any mechanical meaning to 'what possesses a vibration of that amplitude'.

A matrix can itself be treated as if it were a number—with one important and far-reaching proviso: unlike ordinary numbers, in multiplying matrices it matters which factor is taken first. In fact the commutative law of ordinary mathematics is not obeyed by these infinite arrays of symbols, so that

$$q \times q' \text{ is no longer equal to } q' \times q$$

An important application occurs if these symbols are employed in some equation connected with the behaviour of a physical system in motion. In classical mechanics, to fix the behaviour of any set of bodies, it is necessary to know their speed, direction, and position at an instant; from these the subsequent path is predictable. In Chapter I (IV) a breakdown in such causal sequence of prediction was described, as example of Heisenberg's 'uncertainty' which I there preferred to attribute to the principle of 'objectivity' forbidding the measurer to interfere with what he measures. Regarded now as an inevitable feature of the peculiar non-commuting property of matrix calculation, the same breakdown becomes quantitatively assessable. For if a symbol p is taken to denote the

motion referred to some frame of measurement, and the symbol q denotes location also referred to a frame, and these symbols are treated not as numbers but as matrices, then the difference of products

$$pq - qp$$

is no longer zero. For certain specific definitions of p and q, this finite remainder, which for ordinary numbers would be non-existent, is of the same dimensions as the 'quantum' which had intruded—but not so legitimately or naturally—into Bohr's theory of electrons in atoms. The non-zero remainder when a product of matrices taken the one way is subtracted from the product reversed, is accordingly identifiable with universal constants already known; actually the remainder is

$$h / 2 \pi i$$

where i is the sign of 'vector rotation' commonly arithmetized as the imaginary square root of -1, 2π is the ratio of any circumference to its radius, and h is the 'quantum' whose precise magnitude can be obtained from multifarious experiments as $6{\cdot}6 \times 10^{-27}$ erg seconds. This latter was the quantity which intruded into the earlier attempts to reconcile mechanical models of electrical and atomic processes with the facts; it goes back to Planck, forty years ago, but its status has until recent years been that of a numerically verified guess rather than a rational link in a logical chain.

This identification of the difference $pq - qp$, characterizing a non-commutative algebra whose symbols are not ordinary determinable quantities, gives an expression and an interpretation to the Heisenberg 'uncertainty'; this uncertainty is the error introduced by picturing velocity and position as strictly definable in the mechanical sense of allowing prediction of effects from causes. For the quantum is negligibly small if p and q refer to objects of large-scale experience, since h is a very minute amount of energy and time. In such cases the error in causal prediction is extremely small. But if p and q are of the size appropriate to electronic behaviour, the residue marking the inequality of the products is no longer negligible, and in fact sets the essential limit below which changes in the quantities are not knowable or even definable because the spatial and temporal symbols fail to retain physical meaning. Below the magnitude of h we do not know what 'motion'

as spatio-temporally analysed can mean. This is the physical basis of the 'indeterminacy', referred in Chapter 1 (IV) to failure of Causation, and which I traced to the essential objectivity of scientific knowledge.

Important epistemological significance, or light to be thrown on the meaning of knowledge and the truthfulness of science, comes from this associating of the limitations to causal predicting with the rewriting of atomic physics in the language of the matrix calculus. The situation is most clarified in the work of Dirac. His pioneer discoveries in the 1920's were contemporary with those of Heisenberg, and though his calculations end in physical predictions often identical with those of Heisenberg and equally with the latter verifiable experimentally, the starting point and the underlying attitude of mind is even more radically at variance with causal mechanics.

Dirac defines more carefully what is to be meant by the 'states' of a physical system, by an 'observable', and by the application of the matrix calculus to sets of 'operations' whose 'transformations' can be treated by Theory of Groups. He thus lays down the conditions for fulfilling needs of the kind which were extracted from the modern crisis in science, as described in the critique of Chapters 1 and 2.

The 'state' of a physical system, to all earlier workers had meant its specification by accurate fixing of velocities at given points; we have said that Heisenberg's 'uncertainty' removes the possibility of either knowing or defining these quantities below a certain quantum limit. Therefore, in Dirac's strict reconstruction, a state consists of a definite distribution of PROBABILITY over a whole range of POSSIBLE configurations of the system; he thus typifies the modern scientist's (and indeed logician's) preference for a knowable degree of probability instead of a fictitious claim to certainty.

His insistence that the most important physical quantities are to be connected, though not always directly, with the notion of 'observable', might be thought a commonplace of all experimental science: strangely, the insistence is only recent. It is also remarkable that the insistence has come most strongly from the most abstract of theorists, the Ether having been removed from the physicist's dictionary by Einstein, and Bohr's and Rutherford's electronic

orbits removed by Heisenberg and Dirac. But an Observable is for the post-Dirac physicist not merely the 'pointer readings' by which Eddington typifies the experimenter's perceptual experience, such as the location of some indicator on the dial of an electric meter. Generalized to the fullest logical extent, an observable is any quantity which in principle is not intrinsically unsusceptible of measurement at some instant: it may or may not be within practicable reach of our present apparatus, but it must not be inherently inaccessible like the Ether or like Bohr's orbits which were mechanical concepts in the mind and involved self-contradiction when the mechanical specification is followed out. Some writers, including Kemble in his large treatise on Quantum Mechanics, have used the term 'dynamical variable' in place of 'observable', as allowing the widest variety to combinations of the simplest physical ideas of inertia and change of position with time; thus Momentum (product of mass and velocity) is in principle an observable, though in practice it only avoids the final contradiction by subjection to the probability limitation of the Heisenberg Uncertainty which has here been described.

It is therefore inevitable that the symbols p and q which we used, though originating in quantities playing the role of momentum and location, will involve 'probable' and not 'certain' inferences in any specification in the atomic domain: they will there not have the accessibility of their large-scale prototypes of perceptual origin, or else their products would 'commute' and not leave the residue which we had to associate with the quantum 'h'.

In Dirac's work each observable is associated with an 'operator', and his operators obey the same non-commutative law as matrices. This allows his physics to take over the wide experience in calculating matrices which abstract mathematicians had developed with no thought of 'things' or of even idealized perception.

But a matrix was, as discussed above, an infinite array of symbols: so what is an Operator, to be treated according to similar laws? Kemble's treatise, already referred to, defines an operator as 'merely a rule for transforming one function into another'. Many combinations of what Eddington happily called 'a signal to us to perform some mathematical manipulation' are precisely expressible as operators. To take a very simple instance, the 'rate at which a quantity alters as we progress in time' and 'rate of

alteration as we proceed in a given direction' enter into the functions denoting energy and momentum of a changing system, and a symbol denoting the whole process of obtaining such rates of variation may be an operator. Dirac then treats the symbols as if they were ordinary numbers, with certain extraordinary properties such as lack of the commutative law of multiplication.

Among operators much used even in the older physics are the 'divergence' and the 'curl' which can operate upon certain 'vectors', i.e. upon quantities specifiable by their direction as well as by their magnitude. The 'divergence' operator represents the extent to which lines of force spread out or converge into a less dense or denser packing, in any imagined diagram of a space with physical properties such as that surrounding a magnet. For instance, in a fluid the rate at which material is constrained to spread from a region can be expressed by applying this 'div.' operator, and in heated regions it expresses the existence of a falling temperature or of some source of heat. The 'curl' expresses the vortex or whirlpool properties of fluid motion, and 'div. and curl' are essential specifications in connecting magnetic with electric properties in light, radio, and other radiations in empty space and in matter.

Their very economical shorthand, superior to any mathematical language otherwise used in physical science, permits widespread extension beyond elementary conventions: for the vectors operated upon are not merely specified by directions in the three-dimensional space of perception. There is no limit to the number of dimensions capable of this treatment, and we might use for example Eddington's 'phase-space of 136 dimensions'; when treated by operator calculus Eddington calculates therefrom the physical constants of Nature, and finds that their numerical magnitudes show interesting and important agreement with experiment, though his colleagues have not all made up their minds as to what such agreement implies.

Dirac's identification of operators with his carefully defined 'observables' is therefore important as adapting a powerful manipulation from abstract symbols to cover a large class of quantities possessing essential though indirect relation to experience. It is typical of the epistemology implicit in recent physics, that the more remotely abstracted the symbolism from the older science's contact with perception, the more closely manipulation of the

operators and matrices may often be found to satisfy the crucial test of verifiable prediction in experiment. Compared with the successes of the more abstract and non-mechanical symbolism, many of the earlier misfits between fact and theory seem now to have actually been due to demanding that atomic processes must be describable in the same language as employed for large-scale perception: to assume an atom is a small-scale model of causal laws demanded the appropriate 'medium' or 'path', and the resulting Ether or Orbit was an imagined construct, the pursuit of which led to contradiction.

Freedom from unfounded faith in the restricting notion of causal mechanism, and attainment of unimpeded contact between mathematical deduction and experimental test, is therefore characteristic of the era in physics initiated by Heisenberg and Dirac. But we must accept the price to be paid in mental adaptability, when we find that the symbols we manipulate are abstract and mock us if we ask of them what it is that they 'stand for'; a matrix does not so readily raise in the mind a picture in the shape of some tiny miniature of what we see or touch or hear, but it is more apt to bring verifiable answer to our queries. That in pursuing such answers we have given up the desire to know what an electron IS or what it is like, is healthy recognition that scientific knowledge contains truth but not always the truth of DIRECT perception.

(II) EDDINGTON'S VIEW OF SCIENTIFIC KNOWLEDGE AS OF 'STRUCTURE'

The removal of the Heisenberg and Dirac type of calculation from APPARENT attachment to 'things perceived', has been associated paradoxically in the previous section with a need to eliminate the inherently unperceivable from physics. Instead of picturing the state of a physical system in terms only of models akin to objects of perception, the modern theorist renounces the pictorial method and expresses interrelation of the observables by his manipulation of symbols in matrix and operator calculus. This implies a shift of attention from 'things' to 'structure of relationships' : what the relata ARE in DIRECT terms of perception and the world of large objects, is no longer of paramount interest, provided that the theory includes a long enough chain of inferences to predict more

correctly though INDIRECTLY the actual measureable facts. These latter are often remote in character from the old imagined picture of the 'things' of which the atom was supposed to consist, and may, for instance, be the shifted frequencies and modified intensities of radiation, measureable on a photographic plate with an accuracy subject to error of no more than one in millions.

Sir Arthur Eddington is the writer who has seen and expressed most clearly this swing in the notions of truthfulness towards emphasis upon structure instead of upon things. The present section can be very brief, because, unlike the topics of most of this essay, Eddington's theories are already as lucidly expounded as they are ever likely to be, in his own masterly and inimitable style. What I have to do, however, is to dissect out his view of knowledge as 'structure'; since I shall in a later chapter give reason for a feeling that the 'subjectivism' with which he invariably brackets it has not the same permanence or power to convince.

What is it that possesses structure in physical science?

(a) In the older physics, structure was attributed to 'things' or 'objects' and their 'material constituents', such as molecules and atoms, and far back in Victorian days the various imagined Ethers were also sometimes given a structure and elastic properties.

(b) But as soon as in the relativity of Einstein the ether assumed its present air of imposture, the structural properties of space as empty transmitting medium for all radiation were diverted from the 'thing' to the logical relationships which survive our scepticism about the 'thing's' existence: these logical relationships for empty space are the Maxwell and Lorentz equations connecting magnetic and electric fields and their motion. Their structural properties are very important and reappear in the wave equations of the electron formulated by Schrödinger which have contributed much to modern treatment of atomic problems.

It is not inconceivable that the mathematical structure of our wave treatment of matter will survive our belief in 'matter', just as Maxwell's equations have survived a dead belief in an ether.

(c) In the work of Dirac and Heisenberg, the structure is that of the transformations which permit selection of those physical relations capable of exhibiting invariance (Chapter 2), and so allow the turning of individual theory into widespreading applicability. The laws which associate such relations, and allow their manipu-

lation, are laws of the same kind qualitatively as the law underlying 'two and two makes four'. They are laws which I referred to in Chapter 1 (VI) as examples in intuitive induction. After Chapter 4 it may become possible to see where they belong in the wider logical notions unearthed by Bertrand Russell.

(d) In Eddington's own writings, the structure in physics is that expressed in the Theory of Groups. This latter he vigorously claims as the sole way of escape from the 'infinite regress' or 'explanation of the explanation of the explanation ——' that would turn the infinite variety of Nature into a trackless jungle.

Eddington thereby reduces to quantitative form the requirement which I regarded in Chapter 2 as replacing faith in Causality, i.e. 'every event can be analysed into a LIMITED number of independent elements'; this requirement is equivalent to a confidence that ultimately 'Nature is intelligible'. Without some such limitation of liability there would be no point in attempting to make sense out of observations of the external world. Eddington's emphasis on Group structure covers the atomic physics which I have here been discussing; for in the 'operator calculus' to which both Dirac and Heisenberg have driven us, the sets of operations obeying the essential restrictions do exhibit the properties of a Group, using this term in a precise and limited way. In Eddington's view these properties have endless generality: in his own words: 'What physics ultimately finds in the atom, or indeed in any other entity studied by physical methods, is the structure of a set of operations.' We can describe a structure without specifying the materials used, and in this case the individual operations composing the structure may well remain unknown so long as only the mode of their interlocking is known. It is the mode of interlocking of the operations, not their individual nature, which 'Is responsible for those manifestations of the external universe which ultimately reach our senses. According to our present outlook this is the basic principle in the philosophy of science.' 'Our account of the external world must necessarily involve unknowable actors executing unknowable actions. How in these conditions can we arrive at any knowledge at all? We must seek a knowledge which is neither of actors nor of actions, but of which the actors and actions are a vehicle. The knowledge we can acquire is knowledge of a structure or pattern contained in the actions.'

Here in Eddington's picturesque simile is the epistemology implicit in the quantum theorists' revolution; they had found that, by abandoning pretence to know what the electron is and what it is doing, we can free ourselves to embody in matrix calculus or operator calculus the transformations which exhibit a structure. Then from the equations in that structure we deduce predictions verifiable in such concrete measurements as the displacement of a streak on a photographic plate.

It may from these considerations be evident that the truth of a theory is no longer a correspondence between small-scale atomic model and large-scale perceptual objects, but some property ascribable to a 'pattern' and to be judged as a pattern. The criterion may well be that of coherence within the pattern. The logical form of such pattern, and possible practical criteria, I attempt to deal with in Chapters 4 and 5; but meanwhile it will be worth turning aside to exemplify this 'structure of relations' in the new relativity of Milne, which has too seldom been regarded as relevant to the Dirac, Heisenberg, Eddington stage of physics.

(III) MILNE'S RECONSTRUCTION OF PHYSICS UPON THE CORRELATION OF TIME EXPERIENCES

Any introduction to Milne's new treatment of physics may also here be brief, since in another publication I have used some hundred pages in an account of it. But I was there concerned with Milne's theories as exemplifying the use of concepts of Time, particularly in Relativity and in Astronomy; here I must extract instead the contribution that his analysis of temporal relations can make towards the new scientific truthfulness which is a coherence between logical relations instead of an acquaintance with material things.

In contrast to Heisenberg's and Dirac's work, where epistemological novelty was enforced by the needs of atomic research, Milne's theories have so far had little contact with atomics and electronics and quantum physics; they set out from a criticism of relativity. Milne reconstructs the Lorentz–Einstein transformation by which the earliest relativity enabled laws of Nature to become independent of the uniform velocities of observers, and he also

introduces a very novel interpretation of the spectral line displacements which had provided the 'expansion of the universe' as a real recession of the distant nebulae in later versions of general relativity. These items in Milne's physics, together with a complete rebuilding of gravitation and much of mechanics, arise spontaneously and indeed inevitably from investigating what connections must exist between the time-order in which one observer's experience of external events arranges itself, and the time-order presented to other observers. For one of these sequences to exhibit definite relationship to the others, for instance a relation of congruence between any systems of time recorders, certain conditions are shown by Milne to be inevitable: analysis and quantitative formulation of such conditions yields by strictly formal inference such 'physical' laws as can found a mechanics comparable with those of Newton and of Einstein. The comparison however exhibits significant differences, which indicate that the time-scales of classical or Newtonian or EMPIRICAL physics and on the other hand of Milne's *a priori* physics are not identical. These time-scales are related to one another by a logarithmic equation, such that equal intervals on the one scale correspond to ever diminishing intervals on the other, and an infinite regression backwards on the one corresponds to a zero or a beginning about 2×10^9 years ago on the other.

The resulting dualism pursues us throughout physical and astronomical science, each of the two time-reckonings defining one aspect of the material world which is perfectly correct within its own domain of argument. For instance, reckoned according to the one time-scale, the distant nebulae do recede as Eddington and Lemaitre had expounded in the theory of the 'expanding universe'. But reckoned on the other time-scale the nebulae are stationary, and the red shift of their spectral lines denotes instead the alteration of the time-unit when light has travelled so long and so far from these objects which are so distant that the light has occupied millions of years in coming to us. For the emission of that light occurred not so long after the 'beginning' of the one time-scale. The comparison of this 'spectral displacement with age', and the Einstein shift of conventional relativity, and also De Sitter's 'spectral shift with distance', I have commented upon in detail in the book to which reference has already been made.

For the present concern, the most important point to notice is a paradox comparable with that of Dirac's combining of abstract symbolism with abandonment of the unobservable. Milne, building upon logical deductions from the requirement that time experiences must become capable of quantitative correlation for science to be possible, has like the new atomic theorists the air of reliance on formal and *a priori* rather than material argument. Yet, like them he brings from the most formal a closer contact with the observable. Milne is, in fact, the most complete exploiter of the empirical element in scientific knowledge, in that he reduces the basis of physics to man's experiencing of the temporal passage of events as found in our individual and indisputable consciousness. He sets out from the one inalienable fact in our experience of the external world, namely that we do find events ranging themselves into a time-series: but he reveals unexpected worlds of 'physical' theory, as rigid inferences from the logic of demanding that these time-series for differing observers must cohere among themselves by a quantitative pattern of correlation in order for any wide-spreading laws of Nature to emerge. The Lorentz transformation is the first demonstrated by this novel rationalism.

This classifies Milne among those who believe, with Eddington, the view so offensive to conservative experimenters, that 'physical' knowledge may actually be acquired by processes of deductive inference from first principles—and epistemological principles at that. But it also places him at the head of those whose physics is grounded in experience, since the elements which his logic must manipulate, as the relata in his inferential STRUCTURE, are the most fundamental of our quite passive acceptances from the external world, the time-sequences or natural orders in which we discover the world's events.

Any classification must therefore also record Milne's new approach to physics as reinforcing, as strongly as Heisenberg and Dirac, Eddington's insistence that in acquiring quantitative knowledge of the external world we pursue not Things but Structure of logical relationships. With the atomic physicists, the elements to be related are symbols denoting operators, and the coherence of the knowledge may be assessable by Group theory: the contact with experience is guaranteed by the ability to predict verifiable facts, but it is not yet clear how the long intermediate chain becomes

traceable to its end in perceptual experience. In Milne's relativity, the elements to be related in the logical structure are the serial time-orders of differing observers' direct experiences; the anchorage of theory to inescapable fact is so close that a novel step in epistemology seems to have been made and may have wide consequences in physics and philosophy of science.

Chapter 4

ASSESSMENT OF THE NEW APPROACH TO PHYSICS IN THE LIGHT OF SOME RECENT LOGIC

(I) WHITEHEAD AND THE CONSTRUCTION OF SCIENTIFIC CONCEPTS FROM THE EVENTS OF EXPERIENCE

If truthfulness in science is a quality characterizing, as Eddington suggests, the propositions which embody a knowledge of *structure* and *not of things*, its alignment with other meanings of truth must present the problem of connecting logical forms with experiences. It will be impossible to shirk indefinitely the need to connect the terms of the physical dictionary with those terms in the psychological dictionary which describe perception. I have shown enough of the Heisenberg and Dirac methods to indicate features of hope but of great difficulty in this respect, and have pointed out how Milne's relativity offers facilities not available in current atomic theories.

The lack of progress in connecting a physicist's concepts with his perceptions marks the most disturbing contemporary gap in the philosophy of science, and constitutes a prime demand upon the intellectual enterprise of the coming generation. It is worth pointing out that ultimately no one of the following avenues of approach must be neglected.

(a) Logical steps must be traced connecting an observer's individual perceptions of an external world with the terms he wishes to embody in his equations.

(b) Psychological steps must be traced in the growth of any basic concepts in the physicist's mind.

(c) The status of the experient must be decided, as conditioning his apprehension of his 'external' world and as influencing his formulation of his accounts thereof.

Some of the questions involved in (a), with also some excursion into (b), belong here to our Part I: the remainder, with the entire philosophy of what we claim to know in perceiving any external world at all, is not so separable from metaphysics and belongs to Part II.

Milne's physics, with its clear-cut segregation of the empirical element into the correlating of the time-sequences of events, and its equally clear-cut subjection of this element to rational chains of demonstrative inference, offers material already for the kind of analysis which I called (a), compared with the much greater complexity and difficulties of definition in a Heisenberg or Dirac 'observable'. But no attempt has yet been made to treat logically or psychologically the post-Dirac or post-Milne era of to-day with the thoroughness of A. N. Whitehead, analysing a generation ago the concepts of the Lorentz and Newton–Maxwell eras. Whitehead's work of 1919–25 was the first explicit approach of the type (a), and offers valuable guidance for the future, though the subjects of physical interest ran beyond his treatment when Heisenberg began to write, about 1925.

Whitehead set out from the fact that the uncritical scientists and logicians of the pre-relativity age had commonly invoked Time and Space and Matter as fundamental in the physical dictionary. Secondly, the Einstein and Minkowski stages in earliest relativity, 1905–13, had emphasized that what we actually observe are EVENTS between which the intervals may be Time-like or Space-like according to the situation and velocity of the observer, so that no single or absolute partition of intervals can make spatial experience independent of temporal. Thirdly, psychologists such as James Ward, between 1910 and 1920, had shown that the concepts of Time and Space are mental constructs acquiring much from memory and imagination and only distantly founded in perception of spatial separations and temporal successions and simultaneity and duration. The concepts as used in physics possess a continuity which makes them amenable to mathematical treatment in differential equations, where they are shorn of the emotional control contributed to the perceptual elements by the mental processes involved in memory and imagination. Thus perception, and on the other hand the concept of Time in ordinary thought, and the concept turned into a mathematical variable, all imply

very different meaning. It was therefore not unexpected that Time and Space invoked as the concern of physics should require analysis, and are indeed examples of that process of 'abstraction' noted in Chapter 2 as a large fraction of the scientist's work in reducing experience to calculation. Whitehead was the first to elucidate the LOGICAL steps in the growth of those concepts of the older physics, though A. A. Robb had previously described in mathematical form much of the genesis of spatio-temporal relations.

Covering all such abstractions from experience as can be included under properties of 'extension', notably temporal and spatial, Whitehead worked out the detail of a 'Principle of Extensive Abstraction'. This demonstrated how finite durations of events, representable by geometrical figures, can by the relations of overlap and the processes of converging series be reduced to a logically rigorous set of definable abstractions. The relation of congruence between these abstractions provides an account of the essence of physical measurement, and exposes just what precision can be extracted from our looser attribution of experiences to 'time and space, etc.', and other notions which used to be thought fundamental in science.

The 'elements' of an exact science appear in Whitehead as the events which are the relata of the logical relation of 'extension': for these events extend over one another and form parts of one another, and this property of extending gives rise to what he termed the externality of Nature and to the most abstract notions of Time and Space. 'Objects' then come into experience by our recognition of events, the changes in an object arising in the diverse relationships of 'something', which is supposed more permanent, to different events in succession. Abstraction in turn from these objects gives rise to the concept of 'matter'. The SENSE-OBJECT is the simplest permanence traceable as identical throughout a succession of events; but PERCIPIENT EVENTS, EVENTS WHICH ARE THE SITUATION OF THE SENSE-OBJECT, and CONDITIONING EVENTS, can all be distinguished in the external relations of a sense-object such as for example a particular shade of some colour. PERCEPTUAL OBJECTS represent the more permanent possibilities of sensation, such as a building or some geographical feature which is recognizable as an association of sense-objects in the same continuing situation. Only non-delusive perceptual objects can be called PHYSICAL objects,

and SCIENTIFIC objects such as the electron are removed a stage further in the process of mental abstracting.

Whitehead's brilliant analysis has not maintained the hold over scientific attention which it seized in the early 1920's. The reasons seem to me, firstly that the concepts such as Time and Space and Matter, upon which the Principle of Extensive Abstraction could be fully expended, ceased about 1925 to be the points of focus of physicists' interest which they had been for the previous half-century. Secondly, the form of the analysis was geometrical, a method somewhat distrusted in current science; thirdly the underlying idea of connecting physical symbolism to perception was at that epoch anchored to the Minkowski merging of spatial and temporal concepts. This was useful geometrically, and served well the Lorentz transformation whose nature was perhaps not understood until the days of Milne, but it was philosophically very misleading: temporal experience may be more fundamental than spatial. This third defect of the Whitehead analysis was, I think, an irremediable mistake, but the other two merely imply that the method must be simplified and redirected to the shifted interest of a post-Dirac and post-Milne era. However, as the pioneer and only thoroughgoing attempt to recognize and meet the need for connecting logically the scientific concept with its perceptual ancestry, it stands as permanent example and challenge to comparable enterprise—if an investigator of comparable brilliance could be found. The structural elements in the symbolism of Heisenberg and Dirac are at least as worthy of the attention of a future Whitehead, and, most of all, Milne's relegation of the perceptual element to time-successions might repay analytical study for linking the scientific concept to the experience of the individual observer.

(II) BERTRAND RUSSELL AND THE LOGIC OF PROPOSITIONAL FUNCTIONS, TRUTH, CLASS, RELATION, ORDER

If Whitehead's tracing of logical steps, between perceptual experience and the concepts used by the physicist, has failed to prolong its usefulness into the present age because of emphasis shifted on to novel topics, we might expect to gain something to meet the

newer needs if we go back to the more fundamental logic from which Whitehead drew his methods. There can be no doubt that Whitehead's brilliant but impermanent treatment of the physics of the 1914 era utilized the extraordinary development of pure logic which had enabled him in 1910 with Bertrand Russell to set mathematics upon its feet. That collaboration followed the work of Frege, Peano, and others, and was followed later by Nicod, Wittgenstein, Ramsey, and others; at an early stage in this revolution, mathematics emerged in the hands of Russell and Whitehead as a system of reasoning not separate from logic, and not dependent on the specific notions of extension and magnitude, discrete or continuous, which had formerly associated it with the empirical. Mathematics began to appear as consequence of the same principles which underlie any complex thought, in fact the most basic principles of logical classification and inference. Russell's own excursions into physics, notably *The Analysis of Matter* (1927), as well as the studies for all future quantitative treatment of symbols, the *Principles of Mathematics* (1903), and the *Introduction to Mathematical Philosophy* (1919), contain, I think, possibilities for guidance less ambitious but perhaps more lasting than Whitehead's own applications to his particular and evanescent stage of physical history. If Eddington's interpretation of the Heisenberg–Dirac era, and my appreciation of Milne's feat in basing physics upon time-sequences, both tend towards an emphasis that scientific knowledge is the apprehension not of things but of the structure of logical relationships, it is to Russell's older work that we must first look in foreshadowing a future philosophy of physics. We must, in fact, follow up the quotation from Russell stressing the importance of 'structure' which Eddington himself has more than once reprinted at the head of his chapters.

To begin with, in this section consider which of the advances in Russell's logic have relevancy to the situation left after our analysis of Heisenberg, Dirac, Eddington, and Milne; if physics is primarily a structure of quantitative but often abstract relations, it needs a definition for the truth of its propositions other than the conventional correspondence of mechanical model to classical theory.

It will be of special importance to the present problem to see what precise meaning Russell gave to a distinction between 'pro-

position' and 'propositional function', since neglect of this distinction makes nonsense of very many questions of the truthfulness of a scientific argument. He also provided definite meaning to the notions of Class, Relation, and Order. These will be briefly noticed now, keeping in mind that they have not always gone unchallenged: for instance the treatise on logic by W. E. Johnson, before referred to, discusses rather differently the material underlying Russell's Propositional Functions.

Propositions, commonly statements asserting that something has or has not a certain characteristic, are often usefully taken as the 'bricks' out of which any structure of reasoning or argument is to be built; the relation of Implication between propositions or groups of propositions is then a structural property whose assessment can contribute to our judgments of truth. It is of the final emerging proposition itself that 'truth' or 'falsity' might be predicated, but it is seldom possible to make such a decision unambiguously about many modern scientific propositions; the multifarious qualifications of truthfulness have given rise to the whole assemblage of difficulties in interpreting scientific explanations of Nature, which I have quoted in earlier chapters. For instance, what kind of truth is contained in the wave-equations of the electron or in the particle-equations of the same electron? Do they imply any truth in the proposition 'the electron IS a wave phenomenon' or in the proposition 'the electron IS a particle'? In the older logic of science these two would be incompatible. Russell claims that many difficulties in deciding whether statements in science or in common life are true may be avoided by his view of Propositional Functions, where the correctness of a Form may be valuable without decision as to the truth of some of the propositions included under that form. We may learn similarly to use a wave equation without demanding whether something is a wave.

'Function', either in mathematical physics or logic, denotes the dependence of one quantity or one character upon another quantity or character, in the sense in which we say that volumes and pressures in a gas are functions of its temperature, any one of the quantities being fixed by the fixing of the other two. Just as a function thus expresses the behaviour of a VARIABLE whose value can have a whole range of magnitude, and the FORM of the variation is seen in the function before individual instances or values

are inserted, so a Propositional Function extracts the form of a whole range of propositions. It is, in fact, a verbal or symbolic expression containing one or more undetermined constituents; these constituents are such that, when values are assigned to them, the expression becomes a proposition itself. The expression is a functional form whose separate values are propositions. Its use is wider than the mathematical, but the step which it takes beyond the mere judging of individual propositions is analogous to the step of investigating algebraic forms instead of taking the arithmetical instances one by one. Any mathematical equation is a propositional function, but in common argument we also utilize the notion: for an extremely simple example, 'x is human' is a propositional function, since so long as x remains undetermined we know only the structure which is neither true nor false, but when a value is assigned to x it turns into a proposition which is either true OR false. For the more complex arguments of recent physical science, if will often be highly illuminating to throw the theories into a shape revealing the propositional functions, and so to decide how much of the Eddington-defined 'knowledge' we acquire before becoming involved in the query (perhaps unanswerable) as to whether the associated propositions will be true or false.

In general, the propositional instances themselves confer the possibility of truth of a propositional function, which itself is not often intrinsically true and can only be labelled as formally satisfactory and sometimes true. There are, however, important limiting cases where the propositional function is 'always true' or 'always false', and its every associated proposition has the same one of these two characteristics: for instance the principles of deduction and all the primitive statements in logic consist of assertions that a given set of propositional functions are true for all possible propositions. This would correspond to a functional form satisfied for all values of the variable—an extreme case.

In Russell's treatment, many traditional insoluble puzzles become clear, including the meanings to be assigned to the words 'necessary', 'impossible', and 'exist', which were ambiguous until statements were classified into propositional functions and propositions; the 'truth' thereby can be segregated into the portion of any argument which concerns the APPLICABILITY of a theory rather than its FORM or structure. It is the essence of this essay to suggest

that corresponding segregation of (a) structure and (b) the identification of examples to come within the structure, may remove much of our anxiety as to whether electronic or other explanations of Nature are to be called 'true'.

The analysis of any scientific theory might also gain from other cases of usually vague notions brought to definite meaning in the logic initiated by Russell. He takes the idea of the proposition as the most fundamental in reasoning, deriving thence the idea of 'classes' by which we begin all our analysis of experience. Classes can overlap, and the notion of 'inclusion' of a class within another class, the notion of the subsumption of a concept in another concept, and the notion of implication of a proposition within a net of other propositions, can cover a very wide range of the topics previously unattached to basic principles of reasoning. Thus a class is the extension of a propositional function involving one variable, i.e. is the set of values which satisfy the function, so that the function is a method of collecting together all those propositions included under its form. The notion of ORDER is also important for scientific reasoning, both when treated in the sense of 'pattern' or 'structure facilitating inferences' in contrast to the chaos of individual opinion which inhibits scientific knowledge, and in the narrower sense of one-dimensional serial order such as temporal or numerical. The notion of a RELATION, essential to all logic of the sciences, can also be derived in terms of the propositional function, since relations are a CLASS of ORDERED couples or trios, etc. Just as any class itself is the set of values satisfying a propositional function involving one variable, so a RELATION is a set of values which must satisfy a propositional function involving two or more variables.

The reconstruction of much traditional logic in these terms can transmute a rather inflexible calculus into a weapon for all reasoning, not only powerful but clearly rational; I have introduced here these recent developments because I consider that they suggest as follows an analogous segregation of the theory of physical truth and knowledge, into critique of Form and critique of Identification. We may learn which are the matters debatable in terms of 'truth' and which are to be judged by new criteria, and the meaning of scientific truth may emerge with some recovery of what it lost in the mechanical era.

LOGIC FOR NEW PHYSICS

(III) APPLICATION TO THE STRUCTURE OF RELATIONS IN THE PHYSICS OF DIRAC, HEISENBERG, EDDINGTON, AND MILNE

Analogy is no sort of proof, but it is often valuably suggestive: and the present state of the philosophy of physical science is undoubtedly in need of suggestions. New bridges are required over the gap now widening between 'experiment' and 'meaning of the symbols in the equations', due to the breakdown of faith in mechanical models which has here been described.

Russell's treatment of propositional functions can clarify greatly the distinctions between formal and material validity of argument, and can help us assign some precise conditions and consequences to asserting the truthfulness of any statement; if his forward step was analogous with the step from arithmetic to algebra, some aspects of the step from mechanical model to symbolic 'explanation' in physics may be clarified in the light of somewhat similar distinctions. In fact, the history of revolutions in physical thought since 1925 might well be less bewildering if scientific workers were to follow the history of logic between 1900 and 1930.

Recall the way in which the most primitive quantitative discussion of the external world at first progressed in terms of numerical computation only, each relatum representing only the data of a single experience. When later an algebraic equation replaces the arithmetical, much more can be learnt about the connections into other differing experiences, because the FORM of the equation has implications beyond the single numbers now replaced by the variables x, y, z, ——. In principle, the replacement of merely algebraic by Differential equations involves only an extension of the same notion to the far more significant 'rates of change' of functional dependences instead of to the functions themselves. This is seen at its most powerful in the Maxwell equations of electromagnetism and the wave equations from Maxwell to Schrödinger. But in Dirac, as we have seen, the terms of the equations are not always algebraic quantities or even the usual functions transcendental or otherwise; they represent operations or groups of operations, and in common with Heisenberg's matrices they obey rules such as non-commutative multiplication which distinguish them from the ordinary quantities of algebraic and differential manipulation.

At each stage in this expanding armoury of quantitative reasoning, the assignment of 'meaning' to a symbol becomes more remote from the simple representation of the original experienced datum; and yet we have the paradox that Dirac's elimination of the 'unobservable', and his ability to predict the measurable such as spectral frequencies and intensities, is achieved in a study concentrated upon the FORM of the relationships. His practical power is not weakened but strengthened by the fact that he disclaims any need or desire to 'know the meaning of' his relata in the sense of forming a mental picture of them.

Parallel to this development, so shocking to the older mechanist, we have in logic also a replacement of older by modern emphasis. The early logic of the Aristotelian tradition, indeed the scientific expansion associated with Mill and current in accounts of science right into our century, had not detached itself from 'belief in' and 'unalterable truth of' the propositions of its syllogisms and inductions; lip service only had been paid to occasional cautions such as 'logic inquires not as to whether the original premisses are well-founded but only as to the sequence from premiss to conclusion'. In contrast, Russell switched the emphasis from proposition to propositional function, enabling FORMS to become significant independent of the particular propositions whose terms we do not always require to know.

Putting together both these sides of the analogy between physics and pure logic, the classifications of 'always true', 'sometimes true', and 'formally correct, but materially correct only by identification of each particular instance with the form', can replace in many arguments the older inflexible propositional truth and falsity. This brings hope of seeing what range of utility there is in 'undetermined symbols' such as enter recent atomic physics. There may be added also the valuable precision given to definition of 'class' by 'extension' of a propositional function over one variable, and of 'relation' and 'order' for sets of values satisfying propositional functions of multiple variables. In fact we begin to recognize, as suggested by Eddington and now reinforced from the pure logician's analysis of the nature of reasoning, that FORM and STRUCTURE involves a 'knowable' whereas THING or MECHANICAL MODEL may condemn us to recurrent or perpetual agnosticism about the physical world. In recognizing a system of atomic equations as of some-

what analogous status to a Russell calculus of propositional functions, we lose the discomfort inherited from the Victorian mechanists at 'not knowing what the symbol represents'; instead we settle down with the restored scientific conscience to learning—as we can powerfully—from the structure of the relationships exhibited in the manipulation of the non-commutative algebra of operators and Groups.

At that stage we may possibly outgrow our prejudice against any hint that *a priori* reasoning might have a physical interest. Thus the anxieties quoted in Chapter 1 (V) become less insistent.

We also become content with the status of that other essential but unspectacular task of identifying the 'sometimes' which must qualify the infinite multiplicity in the truth of the propositional function, in this case the identifying of implications to cover some experimental datum.

In such a division of labour, the rational and the empirical appear in healthier and less controversial co-operation as sharing, rather than merely disputing, the burden of scientific responsibility.

The limitations to this analogy linking the developments of physics and of logic are commented upon in Chapter 5 below. Meanwhile other less general but important consequences from the trend of recent logic may be briefly mentioned. From Russell's classification of One-to-One and Many-to-One relations, and his theory of Similarity of Relations and of Relation-number or structure, we discover the rationality of an often dismaying feature of scientific history, namely that when a theory fits the facts we can never be sure that other theories will not fit them equally well. This well-known and disconcerting eventuality is commonly accepted in principle after much disillusionment, and rebelled against in spirit: but it follows smoothly from recognizing with Russell's logic that the relation connecting the external world with perception is of the type Many-to-One and not One-to-One.

In another application, Russell's analysis of the notion of 'order' may be employed, as underlying with the notion of 'class' the meaning of 'relation' which is fundamental in all physical structure; by this means and as a first consequence of the definitions belonging to propositional functions, it becomes possible to see how very near Milne approaches to a synthesis of the physical with the

mental sciences. The gap between physical theory and the individual's experience of the external world, widened catastrophically by so many of the developments which we have quoted from recent atomics, showed its first sign of becoming bridged when Milne found that he could reconstruct relativity and mechanics upon a correlation between the temporal sequences of differing observers' experiences. For these sequences constitute the simplest and also the only indisputable and unambiguous instance of 'order' in perceptual experience; the complexity of future epistemology, or the understanding of how any scientific knowledge is possible at all, is no longer a hopeless enterprise when we find how much can be built upon a structure which only involves the order in which individuals are bound to range the events in their own apprehension of environment. It is therefore not only in the light of its physics, but in the light of its demonstration of sound application of recent logical principle, that Milne's work may prove to mark an epoch. Order, especially the temporal which is the simplest, is perhaps the most ultimate and ineradicable empirical element in science and indeed in all quantitative approaches to environment; if it becomes amenable to precise logical treatment, it ought to serve well the identifications with experience that are needed for extracting the 'sometimes true' for the basic propositional functions into which the structure of science may become crystallized. I shall discuss at the end of the book some of the most general philosophical consequences of having found 'temporal order' to be fundamental in physical fact.

Chapter 5

A PROPOSED NEW SIMPLIFICATION IN THE DEFINITIONS OF SCIENTIFIC KNOWLEDGE AND THE TEST OF ITS TRUTHFULNESS

(I) COMMUNICABILITY

At the end of Chapter 2, recent criticism attacking an older view of scientific knowledge had left surviving the essentials of Measurement, Abstraction, and Transformation, and the construction of FORMS and STRUCTURES for expressing Functional dependence, without retention of any demand for the meaning of the symbols or for models in the mechanical sense. With this development, an assumption such as 'Nature is intelligible' replaces any 'Principle of Causal connection'. A certain degree of relevance in the physicist's mental processes becomes thereby apparent. This relevance towards the logical structure must not be ignored, but is very dangerous to exaggerate lest it acquires spurious philosophical implications.

In the subsequent discussion of those logical structures, Chapter 3 has insisted that scientific knowledge is ultimately not of things but of just such Formal Structure. This insistence was shown in Chapter 4 to be a part of the twentieth-century tendency of all reasoning towards emphasis upon formal relationships instead of solely upon correspondence with any imagined external world of model material.

It now becomes necessary to return to that postulate of 'Intelligibility', to ask whether such mental feature underlying the logic may possibly simplify the meaning of knowledge and truth and allow covering of the requirements evolved in all those chapters.

The essential fact underlying the Intelligibility postulate is, I think, that truth ceases to be a property of the 'knowledge' possessed by any ONE scientist, and becomes a property dependent on

the coherence with which the processes of one scientist's mind are capable of COMMUNICATION into a common state for multitudes of other minds.

Consider how this feature is bound to arise from what has already been said.

The modern reconstruction deprecates decision as to whether propositions about e.g. the 'wave-electron' or the 'particle electron' are 'true' or 'false' in the sense of corresponding to any permanent object with the model properties of anyone's mental picture or concept. The analogous development of modern logic has shown that there is much valuable work to be done without demanding the truth or falsity of propositions, and concerned instead with their form. But the physical task, thus emerging as formulation of abstract relationships, does not absolve from judgments based upon identification with fact: the type of fact has only become more remote from the terms of the equations. The useful but partial and incomplete analogy of the physical to the purely logical thereby shows how much more complex is the physical judgment of truth, compared with its counterpart in the truth conferred upon a propositional function by insertion of particular variables. In each case the decision superposed on the Form comes from check upon the propositions implicated in that form, but the kind of measurement which is to guarantee a wave-equation or other physical equation may only emerge at the end of a long and shadowy chain of argument; the course of it might include selection of the elements of a mathematical matrix and also detection of the blackening of a chemically developed plate, the embodiment of each of which into propositions involves extremely differing mental processes.

I would suggest that the most far-reaching test of the links in such complex chains of argument is COMMUNICABILITY; the degree to which scientific statements are communicable may be very high although connection between measurable quantity and undetermined symbol remains not obvious.

The first stage relevant to predicating truth or falsity about a physical proposition, is that some numerical value assigned to a variable by inference from the formal equations of a theory shall reappear as a measurable quantity, for verification or contradiction by some experimenter. In the second stage, this meeting point

of theory and fact can only contribute towards true scientific knowledge if it becomes communicable; this means, if the physical situation can be written down by means of mathematical Transformations so that all experimenters in however different circumstances can verify the facts by appropriate modification of observing apparatus. The classic instance of this attainment of communicability is the Lorentz Transformation, by which differently moving observers correlate their Temporal and Spatial estimations in Relativity.

Communicability is thus the property which alone elevates the products of a single scientist's mind to the common body of statements acceptable by ANY worker who utilizes corresponding mathematical and observational method. Without this feature of communicability, science would degenerate into chaotic individual opinion or even solipsism. 'I have found this to be so' only contributes towards 'proof of truth' if 'You in China and you in U.S.A. and you in U.S.S.R. etc.', making the corresponding experiments obtain the same answer, or answers correlated by an adequate transformation.

The very fact that 'answer' is often enough remote from theory, carrying the physics far beyond its initial valuable analogy with Russell's logic, constitutes the greatest need for this communicability; for the 'answer' to the physical inquiry is generally a set of what Eddington called 'pointer readings', or recordings upon the dial of some electrical meter or optical comparator or photometer. About these recordings there is no question of predicating truth or falsity as they are just facts, unless there is inaccuracy or incompetence in the human or the automatic machine. But when the facts become independent of the particular laboratory, and are identical or correlatable with the records of other institutions, this sharing of agreement, or communicability, confers upon the propositions describing the facts a sense in which they have become true scientific knowledge. That it becomes precisely communicable, verifiable by all and not mere individual opinion, is perhaps the most ultimate sense in which 'science is true'. Partial degrees of truth approach a limiting probability of unity as the range over which they are communicable becomes ever widened until it covers all circumstances and all observers.

But these collections of communicable facts are apt to be of

greatest interest by the degree of truth that their own validity can confer upon a physical theory beyond them. I have stressed that such theories no longer require mechanical modelling, and that they have the abstract form analogous to propositional functions. The comparing of physics with pure logic shows here the suggestiveness and the limitation of such comparison; the logician may become usefully interested in the isolation and the form of propositional functions, and may leave to others the importation of their truth through the insertion of the propositional variables which refer not to form but to fact. Often the logician would be wasting his time by awaiting the truth of the particular proposition instead of proceeding with research on the functional form. Correspondingly it has been a clogging mistake for physicists to ignore the importance of the abstract forms of quantitative reasoning, and to demand solely the undigested collection of the facts. Even if we do not subscribe fully to Eddington's 'we know only the form and structure', we can recognize that much can be found from the form of a wave-equation without knowing what is the oscillating 'thing'. Some groups of physicist are best employed in such investigation, and the honesty commended in the school of Dirac and of Milne makes no pretence at failing to claim the importance of investigating rational structure. There can be contentment that the abstract forms, like the propositional functions, contain potential truthfulness qualified by the 'sometimes' attached to those functions, and this is as far as we ever reach towards the truthfulness of a physical theory, a limit set by limited communicability conferring truth upon all the separate inferences from the theory. It is a matter of personal taste perhaps, certainly not a matter for dispute over precedence, whether one physicist happens to prefer the aesthetic delight of abstract equations in which truth is only checked by consulting the experimenter, or whether he prefers to work towards discovering the truth which is the communicability of measurements but which lacks its greatest importance until handed to the theorist for treatment by transformation and the extraction of general form. Both groups of physicist must concede the other's indispensability—which to a pre-relativity and pre-quantum age was not so apparent.

One of the most striking examples of this division of labour, and of the essential part played by communicability in conferring de-

grees of truth, is the physics of waves, already often referred to here, in its particular application to the theory of the electron. Whether an electron is 'truly' a particle phenomenon or a wave phenomenon would be, for the older logic of science, a question to be answered 'always the one' or 'always the other'. To-day the wave form might better play the part of propositional function; those accounts of experiments guaranteed by their communicability and exhibiting wave-measurement (such as frequencies) would then confer upon the wave form a possibility of turning the propositional function into a TRUE proposition IN THE SITUATION OF THOSE PARTICULAR EXPERIMENTS ONLY. But there is no permanent truth covering all situations, as quite a lot of electronic behaviour is not wave-like at all, and the desire of our scientific ancestors to 'make up one's mind once and for all what the electron really is' must be resisted. Such desire would not survive the need to be communicable from one experimental situation to another, nor the logician's discovery that much of quantitative reasoning concerns the functional form and cannot cover all the propositional instances but is not thereby to be despised. Each identification of a property associated with a particular form has to be tested by its communicability throughout such situations; but in scarcely any physical theory to-day does the communicability carry over to all situations and confer the universal sort of truth sought by our forefathers, who could not use happily a symbol in an equation without claiming to know for it a fixed and permanent meaning.

(II) COHERENCE

Following the suggestion that the feature of 'communicability' must enter any definition deciding when scientific statements become true knowledge, the need for practical criteria classifies several stages at which 'truth' characterizes different kinds of proposition in science. I have claimed that recent physics and logic both unite in dividing the labour more sharply than of old, into the study of formal structure mathematical and logical, and on the other hand into the identification of experimental facts with predictions based on those formal structures. But the contemporary novelty in the remoteness of the form from the facts, shocking to the generation who relied on theories which were to be copies or

models of Nature, requires there to be distinguished the following, which will involve extension of the notion of communicability and in addition the notion of Coherence.

(a) The actual measurements by the experimenter are in no question of truth or falsity; they are mere fact, so long as nothing has gone wrong with his recording apparatus or his conscience or his trained skill in noting what figures appear on a dial, etc., at what instant. Attainment of factual 'truth' is a matter only of guaranteeing a trained technique.

(b) Truth of the propositions in which the experimenter embodies these observations involves a 'correspondence' between the latter and the various results of abstraction, simplification, classification, and mathematical transformation, which are common to all effective scientific synthesis and were discussed in Chapter 2.

It is essential to realize that here is a correspondence between recorded experience of fact and description of fact, not yet between description of fact and any theory meant to explain the facts, and not between 'concept' or 'model' and 'thing'.

Here again, truthfulness only fails if technique be defective, though the training required to ensure reliability in the gathering and synthesis of experimental fact into the appropriate propositions may take years longer than the training of an accurate observer. Until recently the naïve stages reached by comprehensive physical theory left many scientists under the impression that scientific knowledge and truth involved no further problems than those of (a) and (b).

(c) We now step from the work of the single scientist to that of the scientific community. The 'results' of the former's activity may be knowledge so far as he is concerned, but contribute nothing to the general heritage of truth until they are rewritten in a form communicable to, and verifiable by, all workers anywhere utilizing the appropriate methods. It is a quite inadequate tribute to any supposed Intelligibility of Nature to say to oneself 'I have measured it and have formulated the legitimate propositions conveying it' (these were stages (a) and (b) only). The isolated experiments must next be shorn of all aspects which were peculiar to their time and place and surroundings. This means they become convincing to quite different observers, who on repeating the experiments ob-

tain not necessarily the identical answer but a set of answers transformable into the original one by taking precise account of the changed surroundings. In short, they become widely communicable, and I have taken this communicability as constituting an essential aspect of the truthfulness of any scientific statement. Physicists will recollect how the Lorentz transformation thus renders communicable differing observers' findings about Temporal and Spatial estimates and the velocity of light.

(d) The fourth stage crosses the enormous gap which I have shown separates the whole logic and psychology of recent physical theory from the conventions of the experimenter and of the older mechanical and causal theory. We have to approach the 'truth' of an 'explanation', such as the wave-treatment of 'matter', electromagnetic fields as properties of empty space, gravitation as a function of the curvature of space, etc.

This is harder to judge as to truthfulness, and I shall add the conception of Coherence to that of communicability: coherence will be the test of correlating the widely different kinds of physical situation, within each of which communicability has already guaranteed a degree of truth. Stages (a), (b) and (c) have been the assembling of the facts into communicable and therefore verifiable acceptance; they provide truths but not all the truth hoped for in science. In turning to ask what can further constitute the truth of an explanation of those correlated facts, the analogous use of forms and structures in pure logic will be worth retaining, and also the manner in which particular truthful propositions confer degrees of truth on the propositional function. It is this modern way in which sets of quantitative and communicable experience can confer degrees of truth upon a theory, that has occasioned our whole inquiry, so the discussion may now be in a position to make clearer the appropriate significance of scientific 'explanation' of Nature.

The conception of communicability was previously utilized in the criterion for judging and grouping sets of associated experiments, and may now be broadened. Not only must any experiment be communicable, in the sense that all other experimenters must be able to identify and correlate their own answers to the same problem, but now quite other groups of workers investigating far different topics may find that those answers, reduced to common

terms, offer solution of their own different problems in turn. The communicability extends not only throughout all experiments covering the same kind of physical situation, but is capable of application to distant and unlike situations. An explanation in one branch of scientific inquiry, if communicable in this wider sense of suggesting corresponding explanation for other branches of inquiry, acquires thereby a strengthened title to truthfulness, if the latter is accepted as a property judged as knowledge belonging to the community and not merely to the individual.

One or two examples of this criterion may be useful.

At the beginning of the modern era, the replacement of circles by conic sections as representing planetary paths, implied replacement of a mere geometrical description by a theory which fitted the facts better. Actually the medieval combinations of circular motion fitted the then known facts to within one minute of arc, and the modern ellipses fit only to a greater refinement of accuracy. But the far greater gain was that, unlike the medieval circles, the modern conics were communicable to other situations in the manner we have been demanding. They cover the facts of cometary and double-star orbits as well as planetary, and they were a valuable though transient help at the other end of the magnitude scale in the supposed orbits of electrons within the atom. To the extent of that help, communicability of theories of elliptic paths in gravitational and electric fields conferred a very high degree of scientific truth on this type of explanation. I have commented in earlier chapters on the situation arising when a limit to this truth was reached. The atomic orbit explanation became inadequate when called upon to explain optical phenomena, and had to be buttressed by superposition of the quantum restriction which had no rational status on the then current knowledge. Later extension to the 'situations' of electron diffraction required the orbit of a particle to be replaced as explanation by the wave pattern. That the electron as a particle and the electron as a wave pattern are, in differing situations, each true explanations of the facts, illustrates the novel view of truth: we no longer claim to know irrevocably the nature of the electron, and two quite different theories are simultaneously 'true' as each is communicable over its own range of physical situations. That two ranges of situation involve what the older scientist would call the same electron or same 'thing', is

no longer an anxiety, because 'thing' has vanished from what we demand to know and has been replaced by 'structure'.

All such critique of the 'sometimes true' (in our language of the logician's theory of propositional functions) arises from sets of inferences with limited communicability; our attention is rightly attracted by relationships whose form and structure survive their fluctuating identification in one or another physical situation, but we judge their contribution towards the truth of any scientific explanation by their suggestive though often transient gathering of wider ranges of situations. For example again, the notion of 'energy levels' has played a great part in optics, metallurgy, chemistry, and the theory of how poisons and nutrition can penetrate the living membrane, but the associated picturing of potential diagrams has often misleadingly reached the 'fetish' stage occupied in the past by Ethers and other mechanical models. We ought by now to have learnt that to anchor truth to any one descriptive system is to ask for Nature's mocking in our next experiments: the propositional function is 'SOMETIMES TRUE' and to demand more is to mistake its usefulness.

Perhaps the most striking use of a formal relationship without any permanent assignment of the form to any one 'thing', and yet qualifying by its very widespread communicability for a high degree of truth as an explanation of natural phenomena, is the physics of wave-motion, already mentioned here more than once. The particular structure of the equation marks the wave-treatment, and constitutes the analogue of the logician's propositional function: that function expresses a form to which decision as to truth cannot be permanently attached and must depend on the various propositions to be included under that form. Similarly, much can be discovered by manipulation of the wave-equation independently of whether we can describe in other terms the situations in which oscillation occurs; but whenever a wave-like property, such as a measurable frequency or a diffraction pattern, appears in a communicable set of experiments, then this particular set achieves communication in turn with other situations which have been characterized by wave-like properties. The 'coherence', thus established between the attempts to explain throughout the different branches of physics, confers a new significance of truthfulness upon wave-theory, just as verified propositions confer truth on their pro-

positional function or generalized formal structure. Our inability to describe the material or the medium of the vibration does not vitiate the usefulness of the formal structure, if this coherence can be established.

For instance, we discuss Sound waves, earthquake waves, stationary waves in vibrating machinery, waves on water, the wave-form upon a nerve carrying living processes: in these we do consider we know what is oscillating in what medium. Next there are the wave equations of light or radio transmitted in empty space, obtained by manipulation of Maxwell's electromagnetic fields; here we consider we know what oscillates but we have abandoned all attempt to resurrect the ether or otherwise postulate a medium. Finally there is the Schrödinger wave-equation, by which we nowadays predict communicable facts about electrons and atoms without committing ourselves to 'thing which oscillates' or to medium of propagation beyond saying that the amplitude is a 'probability amplitude'. The work of Dirac and of Eddington, in quite differing connections, has enlarged the communicability of the wave-equation, as in their cases it fits the Lorentz transformation which was referred to before as the first classic instance of widening laws to cover all uniformly moving observers.

Yet this newest identification of wave properties, in the atom, is also an example of the non-exclusive character of the most communicable of scientific explanations: for the electron still fits the mechanics of particles in situations which are alternating with those in which it fits the wave mechanics.

All these cases of explanations partially and transiently communicable from one physical situation to another and anchored irrevocably to none, might be summed up by using the word 'coherence'. The practical test of the widest communicability—and therefore truth—of a scientific explanation of Nature must be in the cohering together of the separated groups of inferences. Each has to be verified by experiment; each is a particular consequence, in some situation however remote, of some aspect of the form and structure of the rational equations or logical relationships. This conclusion is quite independent of any answer to Eddington's query as to whether we discover the logical structure or create it. The coherence between, for instance, the extraordinary range of subjects to which wave-functions apply, may or may not mean only

that our minds 'work that way'—a philosophical problem irrelevant to this Part I of the essay. But it offers the only meaning to saying whether a theory is—for the moment—true or false. This coherence is sanctioned, and in fact only made possible, by repudiations such as Dirac's who rejected the older need to assign a fixed mechanical or picturable meaning to symbols in the equations; some of the most abstract of the latter have been the richest in yielding inferences for experimental verification, and have thus contributed greatly to widespreading communicability of structural patterns in Nature, encouraging physicists to find something better than their ancestors' aim of 'correctly describing the objects of which Nature really consists'.

This word 'coherence' here imported has been, in the history of philosophy, associated with a particular theory of knowledge, Idealism, which preceded the present era of science. Only in Part II of this essay, however, will it be relevant to open the question of philosophical backgrounds and implications to our new use of the term. So far, nothing beyond the cohering of branches of physics united by a common system of equations, or sets of facts associated with a common logical form, has been implied. The discussion has been along the border between physics and logic and has not involved metaphysics in its pursuit of what physicists might mean in aiming at truth in their analysis and explaining of Nature. In Part II it will no longer be possible to shirk the more difficult problem: 'What connects these concepts of the physicist's mind with any external world which may be the object of his perceptions—if there is any external world?'

SUMMARY OF CONCLUSIONS OF PART I

It may serve a purpose of stabilizing the physical and logical aspects of the essay, before attempting the philosophical, to summarize in brief statements for each Chapter the conclusions already reached.

CHAPTER I. Until the era of some recent researches in atomics and relativity, the advances of science were satisfactorily carried forward by alternation of simple hypothesis and experimental test; the quantities mentioned in the former were not unlike those measured in the latter, the nature of hypothesis being restricted to a certain kind which had served adequately from the Renaissance. In particular, the success of early modern astronomy, in replacing geometrical description of planetary motion as imaginary combinations of circles, by actual elliptic orbits linked causally with a theory of gravitation, had set a type of hypothesis in which a cause was assigned for actuating a mechanical model or mental picture. In later uses of this kind of picture, the criterion of truth to be tested by experiment was whether the supposed and imperceptible substances underlying perceivable phenomena act in accord with the Newtonian laws found adequate for the behaviour of visible and tangible objects. Striking success followed the exploitation of this criterion of truth in the theory of gases and of heat, and the electromagnetic theory of light, and some of the simpler theory of metals.

In Chapter I are classified not only these successes, but the stage in more recent physics at which this 'verification turning hypothesis into Natural law' breaks down through inadequacy of the notions of mechanism and of cause which underlay that restricted sequence in scientific method. Crises in these later stages were marked by the failure to 'mechanize' a medium for radiation, by

the adjustment of atomic model through Bohr's quantum postulates applicable also to the breakdown in theory of metals, and by the modified notions of causation required in relativity, and finally in Heisenberg's demonstration of the limits to spatio-temporal definition and prediction.

The enormous expansion of topics and methods in theoretical physics accompanying these crises, has occasioned much controversy as to how far physical science is empirical or rational. I have introduced some new judgment on this in the light of comment from modern logical analysis of the most general processes of reasoning; since various kinds of inference are now known to be interconnected and it ought not to be so tempting to attach 'truth' exclusively to the propositions obtained by only one type of implication.

Chapter 2. Although the last quarter of a century imposes a shift of emphasis from hypothesis and mechanical law, towards instead the devising of patterns of symbols without demand for assigning quasi-perceptual labels to the symbols, other features of the older scientific method survive and in fact emerge as more fundamental mental processes than previously recognized. These features include Measurement, the Abstraction of a logical structure from otherwise isolated experimental observations, and the devising of Transformations required for enabling any theory to adapt itself to differently situated observers and differing scientific situations. Such steps enable the Functional dependences of physics to become intelligible by reducing to the minimum the number of variables to be taken into account.

Chapter 3. The revolutionary developments and suggestions in atomics and relativity, associated with the names of Heisenberg, Dirac, Eddington, and Milne, are here introduced; they demonstrate what kind must be the 'pattern of symbols' to be manipulated in place of mechanical hypothesis and law by contemporary and future physicists. Eddington's emphasis that in physical assessment of Nature we learn to know not Things but logical Structures, is seen in Heisenberg's and Dirac's use of matrices and operators obeying laws other than the calculus of previously considered 'physical quantities'. A corresponding feature characterizes Milne's attempt to reconstruct laws previously empirical by

analysing the structure of temporal relations, a structure rationally discoverable but required to enable different observers to adopt comparable opinions about any external world. The paradox is brought forward that these apparent retreats into the abstract and the undetermined symbol are actually founded in a rigorous separation of the 'experienced' from the 'undetectable', and the 'observable' from the 'inherently indistinguishable': in older theories, these had all been superposed, leading to confusion as to what is and is not legitimate theorizing as contribution to truth in scientific knowledge. A Dirac equation can predict a measurable fact, though often the sort of fact whose description is absent from the abstract and symbolic equation: the new method is actually in closer touch with experiment, though harder on the imagination because it dispenses with the pictorial model.

Chapter 4. I have suggested here that these radical alterations in the method of science and its way of judging truthfulness, may be less bewildering and appear as part of a wider intellectual revolution, if they are regarded in the light of some contemporary logicians' analyses; these suggest how we build the basic notions of science out of the 'events' which are our experiences in which we seem to perceive 'objects', and how our minds classify the elements of experience into relationships permitting inferences to be drawn about future experiences. Whitehead's pioneer attempt to rationalize the unrecognized logical and psychological steps between percept and physical concept had defects belonging to its stage in scientific history, which might be remedied after rebuilding on the newer material of a post-Dirac and post-Milne era. But Bertrand Russell's study of the structures into which can be analysed the form and nature of logical propositions, are found to offer very instructive parallel to the manipulation of symbols and relationships which has emerged from Dirac and Milne. Russell's treatment of Propositional Functions, in particular, points to the great gain of segregating the judgment of Form—involving truth only as communicability and coherence—from the judgment of Fact embodied in true or false individual propositions.

Chapter 5. I have suggested that these trends in physics and logic, thus shown to be converging in unsuspected analogy, may be sim-

plified if we regard science as replacing some of its traditional ideals by an aim summed up in the need for knowledge to become 'communicable' to all possible situations, and thus to be judged as 'true' by the degree of 'coherence' between such situations. The possibility and the use of decisions as to the truthfulness in a scientific proposition embodying experiment or theoretical explanation thereof, are here traced throughout stages of the empirical and the rational in physics. All such decisions are found to be significant only when an 'answer' obtained by one worker becomes, by Transformations typified by the Lorentz, adaptable to expressing also the experience of every differently moving and differently situated observer. Truth becomes a property of the interchangeability between observers, and further the interchangeability of scientific propositions and propositional functions between differing situations. For example a wave-equation in radiation is justified if the experimenter on Light finds his results communicable to the wave experiments of a worker in Radio; the further communicability appears when the same equation fits the behaviour of an electron, showing that the 'coherence' which tests the truthfulness is not vitiated by lack of knowledge of 'the nature of the physical thing'.

Scientific knowledge therefore must lose any claim to be completed in the mind of any single investigator, and becomes judged as the body of interrelated propositions connecting the experiences of a whole community, each member verifying what has to be communicable to his case before it acquires full significance. Communicability and coherence justify the modern atomic theorist and the relativist in their contribution to the 'intelligibility of Nature', so that faith in some such quality in experience can replace the discarded Principle of Causality.

This view of the nature, truth, and test, of scientific knowledge, is complete in outline, so far as the physics and the logic of the problem are concerned. But it leads inevitably to the philosophical problem untouched in Part I, namely: 'What have the communicable and coherent patterns constituting truth in the physicist's mind to do with the supposed Objects perceived as our external world?' That transfer from physics and LOGIC of physics to PHILOSOPHY of physics is introduced in Part II.

PART TWO

PHILOSOPHICAL PROBLEMS OF THE MEANING OF SCIENTIFIC TRUTH

Chapter 6

MISLEADING TRANSFERS OF ARGUMENT FROM PHYSICS TO METAPHYSICS

(I) MATERIALISM AS A METHOD AND AS A PHILOSOPHY

Just as the logical analysis of physical science required to begin with a critique of the aims and methods which had become frozen prematurely among its earlier successes, so any philosophy associating itself with physics to-day must begin by taking warning against premature metaphysics. The first example of such is the hasty materialism which often accompanied Victorian science. As we proceeded in Part I by tracing the gradual interpenetration of advance and breakdown of causal mechanisms, so a clearance may be effected in this chapter by inspecting not only that primitive materialism but also the brief duration of more recent attempts to attain a degree of truthfulness in arguing from the physical world to the ultimate nature of things. Two of those attempts, which I think may well typify the reactions developing consequentially out of materialism in opposite directions, will be Samuel Alexander's theory of 'Space, Time, and Deity' which played a gallant but evanescent part in awakening interest in the physico-philosophical borderline in the 1920's, and Eddington's very Kantian idealism which was as stimulating but perhaps as transient in the 1930's. Eddington's idealism can, I think, be separated here from his logical theory of 'structure' which I described in Part I: the two may come to be judged by history very differently.

It will be essential to distinguish between 'scientific materialism' as a valuable device in methodology, and as therefore confined to the logic rather than the metaphysics and not affording information about anything more ultimate, and 'metaphysical materialism'

as a philosophy offering decisions beyond the range of physics.

(a) The former, in its earliest phase where it was most useful, might well be summarized in a proposition such as 'Measurements yielding numerical assignment of mass, density, elasticity, velocity, position, and similar quantitative description, are capable of correlating an apparently limitless extension of certain kinds of experience where a "physical object" is conventionally taken as underlying our sensations of touch, sight, hearing, etc.'. Modernized variation of such a proposition has been noticed in Part I, where conceptual objects such as Electromagnetic Fields or even Space-Curvatures became more appropriate than Mass-Points at later stages in the history of the science. Description of physics in terms of any of these might reasonably be called 'scientific materialism', whether or not the ultimate conception at any one era had imaginative association with 'small bits of ordinary material'. It is probable that all investigators except a few of the most abstract-minded utilize some form of scientific materialism, and that a varying but small proportion of them would wish to add any metaphysical materialism.

(b) On the other hand, materialism as a metaphysical doctrine would need to be summarized in a proposition such as the following. 'There are no grounds for supposing that anything underlies experience except those same atoms, fields, etc., which we have postulated as comprising the physical universe. In particular, no significance can be assigned to terms such as "mind", "personality", "value", "spirit", except as manifestations of the same atoms and fields and as in principle though not always yet in practice amenable to the same methods of investigation.'

Statements of the type (a) contribute towards the truthfulness of our physics, according to the criteria of communicability and coherence between measurable quantities, as defined in Part I. Statements of the type (b) fail to contribute anything, because they offer to contribute too much. In transposing the useful conventions of scientific method from the language of quantitative measurements to the language of aesthetic or ethical values, metaphysical materialism pretends to grasp and to annihilate notions only expressible in that foreign language which it does not understand. Scientific materialism confines its comments to the Objective world for which its methods were devised, and refrains from

attempting negative but illegitimate conclusions about the Subjective.

The fallacy in proceeding uncritically from (a) to (b), as was popular a generation or two ago, arises from the inexactitude and ambiguity of the words 'physical object' and 'grounds for supposing' in those propositions which I have taken as typical. We are no longer so confident that the only conceivable abstractions from experience are those to be described in the precise but limited dictionary of physics; nor are we sure that 'ground for supposing' includes only those propositions capable of being reduced to Newtonian causal sequences or to Riemannian geometry or to the matrices and wave-forms of atomic argument. Such ambiguity in 'physical object' became evident in Part I even within the analysis of what it could mean to the modern physicist, and led to our reconstruction of criteria of scientific truth. The ambiguity in 'grounds' arises when we recall how many vital decisions have to be taken, and are taken with confidence, without the full sanction of that kind of communicability and coherence which were demanded by scientific truth.

The second of these ambiguities suggests that metaphysical materialism vanishes not merely because the conception of 'matter' vanishes from modern physics, but because the structure of physical argument is now precise enough to realize its boundaries. This possibility will become clearer after discussing the replacement of materialism by Space-Time theories carrying somewhat similar deficiencies in (II).

Meanwhile it will be useful to trace one or two of the ingredients of that mental attitude in which metaphysical materialism and its descendants have been congenial, to see how far from it the critical mind has been brought by other items of the logic imposed by physics in Part I. Materialism was always associated with Determinism; their usefulness together within scientific logic, and their modern limitation and revision inside that domain, point to the abandonment of the one with the other as soon as an illegitimate transplantation into metaphysics is to be criticized. A working plan of research, based upon generalizing the observable sequence of one variable ranging with another in functional dependence, from which plan led the judgment of truth by communicability and coherence, is the modern counterpart of causal

determinism surviving the critique of Part I; it accompanies what I have termed scientific materialism as method, but it leaves us agnostic as to any universal major premiss of induction or any deification of a universal law to be called Causality. Without the latter's support, it is doubtful whether anyone would be rash enough to assert that nothing except predictable interactions between atoms or other 'substance' will ever be encountered in experience. Theories of knowledge and truth confined to the causal laws of the older mechanics might sanction a certain range in theories of existence: such theories might postulate a universe consisting solely of objects resembling in miniature the bits of matter that we touch or picture in the simplest uncritical analysis of sensation. But as we outgrow the usefulness of those theories of knowledge, the really legitimate extensions of scientific materialism no longer enforce or even encourage metaphysical leaps into that darkness of universal negation which intimidated but intrigued the Victorian mind.

Without that premature jump from the functional dependences of physics to a philosophical determinism, all our scientific materialisms are simply the legitimate attempt to reduce what Whitehead called the 'scientific object' to some single denomination; this may or may not be material, according to the convenience with which atom or electromagnetic field or space-curvature or other concept replace each other to-day and to-morrow. These attempts are a valuable part of research, and in no way vitiated by recognizing that they imply no metaphysical status at all. It is also important to insist that this limitation to scientific materialism and determinacy offers no support whatever to theological interpretations of physics, into which some short-sighted ecclesiastics have rushed with as hasty a misconception of science as had led materialists into the opposite stampede. If physics, rightly seen, imposes no materialism upon the most general interpretation of total experience, it also has no more of a positive than a negative attitude to the mental or the spiritual.

More widespread to-day than any philosophy based solely upon a physical but superseded atomic theory, is Dialectic Materialism; this can be looked at without accepting or rejecting its political association. Strangely enough, it is nominally based upon the theories of Marx which Russell has shown to resemble Pragmatism

rather than any metaphysic in their emphasis that 'Thought is led by action and not action by thought'. With this emphasis we would probably all agree, if we each inserted our own definitions of Thought and of Action. It would seem unnecessary to classify under philosophies of physical science a somewhat underlined recognition of the importance of economic factors in the evolution of civilizations, for that is what English admirers of Russian theories usually expound as the 'materialistic interpretation of history'. But as the scientific methodology used by us as physicists has sometimes been linked with Dialectic Materialism, and as the Dialectic is a legitimate and useful method towards truthfulness in many arguments, its association with physics through concepts of 'material' must be noticed.

The Marxian Dialectic is a development of that of Hegel: it is doubtful whether either of these men or indeed anyone in recent centuries could rightly be called its inventor. In the Hegelian form, the most general sequence of an argument is recognized to be by Thesis, through the stage of Antithesis, to Synthesis; in principle this acknowledges that most statements are incompletely true as they stand, and that by admitting in turn the partial truthfulness of an apparently opposite statement we can often clear the ground for a third member of the Triad. This third statement is the Synthesis, which comprises under a wider viewpoint the limited advances towards knowledge achieved by the incomplete and opposing Thesis and Anti-thesis. Progress by such Triads of propositions is a way of describing many of the most hopeful tendencies of thought and argument since the days of the Greeks, and it is unlikely that in any sphere but that of popular propaganda any serious-minded Russian would claim that the founders of his current sociology were the first to realize this healthy view that most truths are only partial. The notion goes back far behind Marx or even Hegel. The Dialectic is of extremely wide utility: we might even discover that the truth about the nature of the universe could be formulated in dialectic triads, the original and crudest Thesis being that the universe is Material, the Antithesis that it is Mental, and the Synthesis that neither of these two incompletely definable categories is wide enough or exact enough or intelligible enough. Whether Alexander's 'space-time' or the geometrical cosmologist's 'space-curvature' or Eddington's 'the knowable is Form, not

Things', can suggest steps to a final synthesis, may be debatable. But one recollects that Hegel always regarded any synthesis as only destined to become in turn the Thesis beginning the next triad in succession, and so on without limit or finality.

It is one of the ironic curiosities of philosophic history, that Hegel's own exploitation of the Dialectic led him along the path of a widening but ever vaguer idealism which associated truth solely with some mental or spiritual reality hard to define; whereas Marx and Lenin led via the same logical device into a narrower materialism. Actually the Russians were concerned to escape from the more objectionable notions which clogged Hegelianism and which were becoming a deadweight of convention to stifle all but the really original Bradley and McTaggart. That Marxists should escape by the very Dialectic which imprisoned the Hegelians is possibly an example of their own contention that 'action determines thought not vice versa'. It certainly demonstrates the inconclusiveness of these relics from the nineteenth century, that materialism should become associated with the same logic which had created its own brand of idealism. In any case, at the present day, in Russia as elsewhere a healthy agnosticism as to what we really mean by 'material' becomes the necessary consequence of recent physics; so that materialism can only revert to the purely physical status whose innocence of any metaphysical significance I have here emphasized. Marx could not help being a child of his century, any more than could the English and other thinkers who had not foreseen the abstract logical neutrality into which the science of 'matter' was shortly to retire. It must not be held to their irretrievable discredit that they too hastily claimed to know what matter was, and even claimed to feel assured that nothing else of importance existed.

If attempted metaphysical decisions based on Dialectic Materialism have no support from the fortuitous historical association of Hegel's logic with reaction against Hegel's idealism, they can thus add nothing to the scientific usefulness and philosophic impotence which I credited to our systems of concepts for correlating measurements. The evaporation of the Victorian conception of material into the more modern but variable one of Structure or Form, leaves the 'object' of scientific thought too neutral to be readily and unambiguously labelled 'matter', 'substance', or

'mind'. The status to be accorded in the future to Causality, if any such notion ever again be given meaning beyond its valuable but restricted physical connotation, may fix some metaphysical bounds to the underlying concepts of a future mathematical physics; but they are not likely to be as neat and unsophisticated as when pictured by the materialist, whose universe was too facile a copy of 'solid bits of stuff'.

An attempt to replace materialism by a more abstract refinement of the regard for 'substance', in Alexander's theory of a Space-Time, must next be considered, especially as it introduces a terminology drawn from the relativity physics of its day. Alexander's metaphysics is not so obviously crude as to state that 'mind does not exist' or even that 'mind is conditioned entirely by the non-mental'. I shall be unorthodox enough to associate with Alexander the idealism of Eddington, which is in one sense the opposite of materialism and in another sense represents a one-sidedness merely complementary to these other philosophies. If Alexander and Eddington both exhibit similar defects it will be noteworthy; they would both repudiate any debt to materialism, though both they and the materialists have in common a notion that the physical science of their day had some access to truth which could lead to information about the entire universe.

(II) SPACE-TIME FALLACIOUSLY TREATED AS A SUBSTANCE

Since the main concern of the essay is the elucidation of meanings of 'truth' and 'knowledge' from evidence as to how we behave as physicists, much of Alexander's work is not relevant here. He was interested primarily in constructing a metaphysics of all that exists—perhaps with McTaggart, who died in 1925, the last of the great philosophers to attempt this impossible task. His theory of knowledge was subordinated to that aim, and somewhat conventionally accepts the assumption of common sense that, in 'knowing', we as individual Subjects do apprehend a completely external world of Objects. He is a Realist in this sense, in contrast to those for whom knowledge involves only the ideas in the subjective mind; in fact his epistemology as well as his obsession with space-time seems superficially scientific enough. At least it has little in

common with the Idealists, whether these derive from Berkleyan or Hegelian or Kantian or go back to Platonic sources. My purpose here is to suggest how closely the Space-Time, which Alexander regarded as some sort of answer to seeking 'what the universe is made from', inevitably resembles the 'matter' of the Victorians.

To what extent does he contemplate a basis of things with all the old properties of 'substance', only altering the name from 'matter' in the fashion of the current Relativity? Is he then an illegitimate example of metaphysical conclusions drawn again from a scientific device, when we have criticized the materialists for the same error? Is this last great attempt to systematize the universe under a single term just another sacrifice to our inordinate urge for imagining we can see all that exists, including ourselves, as product of one kind of thing? The 'thing' might well be labelled with a geometrical name, since Alexander was a child of his age as were the Victorians of theirs when they adopted the label of material. This question of a common urge among obviously divergent philosophies becomes a wider interest than the criticism of a single philosophy, and gives to Alexander's an even greater importance than its somewhat spurious attachment to the Relativity which coloured so much of our physical analysis in Part I. In our concern with metaphysics, solely as it involves the relation of science to truth, the problem of Alexander's work is this: does any meaning assigned to 'truth of a scientific explanation' allow space-time to be more than a geometrical device, and even to explain the relation of Subjective mind to Objective environment? Can the logic of Relativity offer any more valid clue to metaphysics than did the logic of molecular mechanics which in its immaturity was taken to sanction materialism?

Briefly, in his *Space, Time, and Deity* (1921) Alexander attempted to design and fit together a list of 'categories', or terms under which existence and reality might be surveyed, all of them to start from Space-Time as that which in itself is neither material nor mental, but the irreducible from which all evolves. Among these categories are Existence, Relation, Order, Substance, Causality, Quantity, Number, Motion: among the higher products of differentiation of Space-Time are Matter, Life, Mind, and ultimately Deity as the final stage which matter and life and mind are continually strug-

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gling to attain. Deity is thus the end-product, not the origin and beginning as in the orthodox theologies, and undifferentiated Space-Time is instead the source of all creativeness.

There are obvious advantages in such a metaphysics, where a process already known to philosophers as Emergent Evolution allows us to bear the responsibility of creating a state always higher than our own. The ethical driving impulse, which even gives to humanity a creativeness, is very powerful, and it is notorious that the deity as sole creator is the stumbling block in all religions. But the status of the theory, in regard to our problem of scientific truth, may be clarified by the following criticisms based upon analysis along the lines of Part I.

1. To recognize that 'matter' in modern physics is not the ultimate entity, as Alexander does, accords fully with our programme which led to tests of truth in terms of communicability and coherence of the logical structures interrelating observable quantity. Space-Time in such a pattern of logical relationships does have better claim than Matter to be a concept useful in exploring possible descriptions of the physical world. But it does not necessarily outlast a transient phase in the history of Relativity, as may be seen from Criticism 2. It must be remembered that since the days of Pythagoras geometry has been a dangerous basis for metaphysics.

2. Alexander took over uncritically Minkowski's dictum that henceforth space and time were to have no separate significance but only be shadows of a unity transcending both. Subsequent work, for account of which the author's *Time, Knowledge, and the Nebulae* (Faber, 1945), may be consulted, restricts Minkowski's statement to a geometrical demonstrating of the Lorentz Transformation with no metaphysical implication whatever. Alexander himself recognized, in advance of his age, that temporal experience has a meaning not to be covered by treatment of Time as a fourth dimension with Space, for example in his famous *Spinoza and Time*. Nevertheless there is no doubt left, after investigating those brilliant volumes, that Alexander misapplies the whole lesson of Lorentz-Einstein relativity, namely the interdependence of our estimates of spatial and temporal components of the intervals between observed events. For he demands not merely a fusion of geometrical co-ordinates into a single 'entity', but the attribution

to that entity of at least as many characteristics of the old notion of 'substance' as had ever been attributed to 'matter' itself. When he tries to escape from the more substantial properties he has attributed to Space-Time, the latter changes into a conception suspiciously like the Ether, which had so misled the nineteenth century with its pseudo-material impostures. But now, in addition to its other vices, this novel Ether combines with elasticity, etc., the power to engender mind and spirit. A reasonable criticism would seem to be, that it cannot assume powers outside the world of physics unless it renounces the scientific methodology which ties it to that world.

3. At the time when Alexander was writing, Whitehead had valuably shown that our minds abstract the CONCEPTS of Space and Time and of point-instants from the EVENTS describable in the Einstein and Minkowski space-time continuum. I have, in a previous chapter, stressed the importance of thus tracing the psychology of how concepts are developed by abstraction from perceptual experience. But the complete and disastrous inversion of the sequence of scientific logic perpetrated by Alexander becomes evident when he says 'point-instants are real but their separation is conceptual'. Actually it is their separation which is the factual basis of physical knowledge, and of all truth concerning the measurable external world, and the point-instant is the artificially derived concept carried to its mathematical limit.

4. A somewhat similar inversion of the scientific direction in reasoning towards truthfulness occurs, when we compare Alexander's Space-Time with the physicist's 'motion'. J. A. Smith rather cruelly, but quite legitimately, 'dared' Alexander to replace the term 'Space-Time' by the term 'motion'. For Alexander the latter was one of the Categories emerging in evolution out of Space-Time, whereas for scientific logic any concept to be labelled space-time must have rather the character of an abstraction from the actual experiences of motion or of temporal order. In this respect Space-Time fails to have any advantage over Matter, which was also a lengthily derived abstraction and neither a simple object of perception nor an ultimate concept for science and philosophy of science.

5. The only term comparable with space-time, by which Alexander might have forestalled such criticism, is 'Time' itself. Ex-

perience of a temporal order among events is certainly a basic fact in our acquaintance with the physical world, and Milne has recently shown how very large a territory in scientific knowledge can be constructed in all truthfulness by analysing the correlation of these temporal sequences. But such experiences of the temporal ordering of events are individual, and there is nothing to suggest a 'common substance out of which things are made' in any aspect of Time. Indeed Time as a 'thing' is a mere myth, and in logic ought always to be replaced by 'temporal order' and in psychology by 'experience of events as sequences'. The one modern philosopher, namely Bergson, who tried to make a 'thing', almost a spiritual entity, out of the concept of Time, failed by mixing his mysticism with his logic unconvincingly.

These topics are discussed more fully in the author's book on Time already referred to.

The above considerations suggest that the merit of Alexander's metaphysics, as a universe pictured evolving from space-time through matter to life and mind and deity, can be no more than the aesthetic merit of an imaginative work satisfying the desire to picture the world unified. But if judged imaginatively to acquire that merit, it must forego its claim to scientific foundation. It has no right to any support from the physics whose language it so fascinatingly utilizes, and it has no claim to benefit under the criteria of truth which we evolved in the logic of science in Part I.

We may, in fact, confirm all that I suggested as to Space-Time signifying for Alexander what Matter erroneously signified for the earlier materialists, when we see thus that the objections to both types of philosophy are parallel. They each select a concept abstracted from experience by some transient phase in the history of physics, and they picture the entire universe, subjective and objective aspects alike, as built out of that particular abstraction. Alexander's 'substance' is only more modern than Matter, but as little able to bear the responsibility he imposes upon it. The psychology of the emotion, generated in the philosopher's response to such a theory, has much in common with the materialist's satisfaction at his neat and tidy little universe, and we might almost call Alexander's an inverted materialism. It at least refrains from the traditional materialist's tedious contempt for aspects of experience not easily compressible into its restricted framework, such as the

aesthetic. Indeed, once any scientific support is renounced as spurious, it is on aesthetic grounds that Alexander's work may be judged, and judged very highly.

It may appear now, as was hinted earlier, that modern science must withhold support from materialist philosophies not merely by the vanishing of 'matter' out of recent physics, and by the replacement of crude causality laws; for the effect of the logical methods in dealing with successors to matter and causality is even more restrictive upon their hasty metaphysics. The criteria evolved in Part I, for truthfulness of a scientific explanation, must inevitably mark out all these simple compressions of the Subjective and Objective under some single 'substance' as lacking in the coherent communicability demanded of all reasoning to claim scientific support.

(III) CONSEQUENCES OF KANT'S PHILOSOPHY OF TIME AND SPACE IN EDDINGTON'S SUBJECTIVE TREATMENT OF PHYSICS

If a universe described in terms of matter and a universe described in terms of space-time are both such fallacious transfers from physics to metaphysics, is any closer adherence to the criteria of truthfulness secured by introducing a mental factor?

This has been attempted by Eddington, but by means not easily understood without knowledge of their prototype in the philosophy of Kant. So I will briefly outline with comment the Kantian background, to the extent that it dominates this phase of the border between knowledge of truth in science and in philosophy.

Kant's theory of knowledge is not primarily a search for criteria of truth, as we have been seeking it, in tests for the correlation of measurements. His problem is first the reconciliation of the two means of acquiring or constructing knowledge, whose resurrected antithesis to-day appears in our comparison between the Empirical and Rational contributions to physics, in Part I, Chapter I (V). Where his wider version of the problem stood at the end of the eighteenth century may be summarized as follows, somewhat crudely, but perhaps adequately for our particular needs.

The generations preceding Kant had first been impressed by the extent to which in mathematics and logic truthful propositions

could be stated with complete certainty *a priori*, that is, without the collecting of facts from experience. They had then in turn been impressed by the other type of intellectual adventure which was founding modern experimental science, the acquisition of knowledge *a posteriori* by discovery through observation of facts; the latter type of knowledge could not have been evolved *a priori* by 'rational' activity of the mind alone, and seemed to be imposed upon the mind by some behaviour of an external Nature. Thus was defined the method of 'empirical' investigation through our senses. History in the seventeenth and eighteenth centuries had been providing a wealth of illustration for the comparison of these two avenues to knowledge; a somewhat similar comparison is involved in the Deduction-Induction antithesis in logic, discussed under Problematic and Demonstrative inference in Part I, Chapter I (VI), where that notorious antithesis is shown to be inadequate and sometimes misleading. The prime question confronted by Kant was, therefore, why does *a priori* knowledge apply to the facts provided by the senses? Why does that which comes from the mechanism of the Subjective, or the mental, apply to that which arrives from the Objective or external world of Nature?

Descartes, Spinoza, and Leibniz, had been interested mainly in the species of *a priori* knowledge which is entirely ANALYTIC, such as mathematics, and consists of evaluating the properties inherent within some axioms and definitions, geometrical or logical. These philosophers are accordingly classed as Rationalist in spite of their profound differences on other counts. Locke, Berkeley, and Hume, classed as Empiricist, had been more interested in knowledge as SYNTHETIC, to be drawn solely from the amassing of facts independent of any necessity imposed *a priori* by the mind.

This is the background to the common statement that Kant essentially asks 'How are SYNTHETIC but yet *a priori* judgments possible?' He ceases to ignore the disturbing fact that laws of thought and geometry do apply to the empirical world, and at the same time he admits that the *a priori* contribution to truthful knowledge may be not merely a set of analytic deductions from definitions.

Kant's answer was that knowledge of the external world involves not only the empirical element collected by the senses and provided by the Object-world, but also a rational element provided

by the Subject-mind and comprising some *a priori* principles of complete necessity and universality. In Kant's system two of these *a priori* contributions of the mind towards its knowledge of the external world experienced are (a) the Forms of Intuition, Space and Time, (b) the Categories or Principles of Understanding, such as Quality, Quantity, Substance, Causality. Kant thus mediates between the previously exclusive Empiricist and Rationalist schools, by maintaining that both the above *a priori* necessaries are part of any knowledge which experimental science accepts *a posteriori*. He also bridges the gap between some types of Idealism and Realism, rejecting Berkeley's form of Idealism in which we claim to know only the contents of minds: Kant does not demand that we create the supposed external world or that it has existence only within someone's mind, and in that sense he is a Realist accepting the reality of an objective world as given to us from outside ourselves. It is commoner to class him as an Idealist than as Realist, rather because for him this external world cannot acquire shape without the imposition upon it of our Forms of Space and Time, and the Categories also due to the subjective contribution: the world of knowledge is essentially incomplete and formless without the knower's Idea. In fact for Kant the external world has two meanings; as we see it, as 'phenomenon', it is this joint product of outside and of our own internal mentality, but as it actually must exist without our interference we have no direct acquaintance at all—it remains forever 'noumenon', the shadowy and unattainable 'thing in itself'.

It is in this imposition of the Temporal and Spatial form upon experience by our own minds, that Kantian theories of knowledge are in direct contradiction to the sequence by which modern scientific method led to criteria of truth in Part I. I must refer again to the earlier book on Time, in which temporal order is the essence of the given and empirical; however much the process of correlating individual temporal orders into a fabric of science may employ *a priori* principles, the mental activity of each individual imposes nothing whatever upon his own temporal order. A Kantian epistemology would require a metaphysics entirely incompatible with this logic of physics, that is to say, incompatible with the way we now see that the physicist's mind FINDS, not CREATES, the world which he calls physical.

Beyond this, we need not in the philosophy of science alone involve the argument. Kant's other problems are only of importance here as they led to the exaggerated Idealism of Hegel and the Hegelians, who almost monopolized philosophy at the end of last century. In England, Bradley and Bosanquet and the earlier writing of McTaggart represent the gold in that mountain of dubious ore. Among them all there is one feature to which important answer has been given by Bertrand Russell: the repeated stigmatizing of Time and Space by Idealists as mere unreal figments of the mind is derived from Kant's treatment as Forms of Intuition, and also from his 'antinomies'. These antinomies, in their simplest statement, are the contradictions and inconsistencies in logical formulation of the definitions of 'before and after' and 'between', as applicable to an infinite series of 'instants'. Somewhat similar illogicalities are detectable in many traditional puzzles about a concept of Space to consist of infinite arrays of 'points'. Bradley especially made great play with these inconsistencies; the general line of argument might be summarized 'The concept of Space or Time is self-contradictory, therefore Space and Time are unreal and only manufactured by the imagination'. The stigma not dishonourable in Kant's day had become a mark of contempt. To begin with, such argument is answerable by recognizing that a feature of the external world is not necessarily unreal simply because our primitive logic has not succeeded yet in its unambiguous definition. But further, Russell points out that much of the mystery and inconsistency in the Kantian antinomies of Time and Space are simply fallacies due to misunderstanding of the notion of infinity—a crudity removed by the labours of Dedekind and the modern mathematical logicians. Thus disappears, according to Russell, the main *raison d'être* of the Idealist's dismissal of Time and Space as 'unreal' and the ascription of them to subjective impositions upon some supposed timeless universe.

It seems very probable, therefore, that when Kantians ascribe to the subjective mind itself the temporal and spatial properties of experience, their conclusions are in the first place unnecessary from the point of view of enforcing a metaphysical decision out of a logical error which gave the antinomies; in the second place the Kantian conclusion is also contrary to fact, from the point of view of those branches of physics which can now trace scientific

knowledge back to the correlation of the orders in which events are discovered. The essence of the physicist's world is that the most elementary facts as presented to the passively recording mind are in temporal order, and this order is not created by the mind: time offers a real enough characteristic of Nature, and is not readily to be written off as merely a reflection of what is in ourselves.

It is very remarkable that Eddington's masterly analysis of physical knowledge as the 'apprehending of structure', which I claimed as valid and important in Part I, should disappointingly carry with it a revival of the Kantian tradition of attributing physical features of external Nature to the mind's activity. Eddington's 'selective subjectivism' turns readily into the notion that what we obtain in scientific knowledge is just what our minds inevitably insert into the universe of Nature; the idea is not based on the Kantian antinomies, and has both merits and demerits of its own, but it is open to the most serious of the objections against Kant. It offers as unjustifiable a METAPHYSICS of science, as Eddington's attitude of 'knowing not things but structures of relations between unknown things' offers a wise and justified LOGIC of science. Distinct from Kant, Eddington's own support of his subjectivism comes mainly from the success with which he finds the *a priori* laws of Group Theory to be capable of permitting deduction of facts previously discovered empirically, such as many of the relationships connecting numerical atomic constants. He concludes thence that physics must be just that kind of pattern which our minds are fitted to apprehend; but of the ambiguity as to how far 'apprehend' means 'recognize' and how far it means 'create', the implication of much of his writing falls into the latter with no further excuse.

A curious comment, aside from the assessing of Kantian theories in general, is that Eddington's placing of the onus for physics upon the physicist's mind seems to cancel one of the consequences which had made it welcome in non-scientific quarters: if the physicist creates the physical world, he would need to import a second personality to create the Value judgments which everyone recognizes to constitute our other-than-scientific reactions to experience. For we cannot insert Value judgments, moral or aesthetic, into physics, without destroying its impartiality; pushed to a logical

conclusion, Eddington's subjective mind intruding into physics must surely renounce its powers of aesthetic decision, with the uncomfortable alternatives of either admitting an *alter ego* or agreeing that Value judgments do not legitimately exist. Either of these alternatives would be unacceptable to most scientists, and most of all to Eddington himself.

Other criticisms of this metaphysical phase in Eddington's view of physics might be multiplied; Stebbing has in her book, *Philosophy and the Physicists*, concentrated technical lines of attack, and Jeans from the purely physical side is a different but powerful source of criticism. Joad in *Philosophical Aspects of Physical Science*, accuses him of failing to distinguish between the world known and the actual knowledge itself. Dingle objects under a general condemnation of the *a priori* methods which had led Eddington to such aggrandizement of the Subjective mind. We shall leave the matter here with strong recommendation to the 'non-proven', but with vigorous repudiation of the many theological attempts at grinding axes with Eddington's unfortunate metaphysics. When his philosophical reputation is finally assessed, it is certain to rest more firmly on the 'structure' logic, which was a guiding illumination through so much that we followed in the less metaphysical topics of Part I. As elucidator of the logical status of physics, Eddington led well his generation: as metaphysical speculator, he seems unlikely to do more than exemplify with the materialist and with Alexander the danger of transferring into theorems about the nature of existence the devices which are legitimate technique for physics.

Chapter 7

REALIST THEORIES OF PERCEPTION AND THE EXTERNAL WORLD

(I) SENSE-DATA

Results of the preceding chapter have inevitably been of a negative character, since it dealt with types of philosophy which unconvincingly extended over the knower and the known world some concept such as 'matter' or 'space-time' or 'mind', whereas these could only contribute effectively to the truthfulness of an abstracted physics or psychology. In the next three chapters a more positive result is to be obtained from general philosophical modes of approaching the problem of knowing some truth about the objective world.

The turning point in the sequence is as follows. Part I had evolved criteria for truth, in a physical definition of knowledge of Nature, as communicability and coherence in an abstracted and objective system of relations. Chapter 6 has now expressed the inadequacy of turning such logic of physics into any metaphysics to cover the subjective mind as well as that objective Nature. Instead of further vainly asking what theory of the ultimate character of existence might be provided BY physics, let us ask henceforward what view of experience interesting to physics might be provided by modern critical philosophy. Contribution FROM physics may still be maintained if somewhat similar criteria in scientific use of knowledge and in the most general theory of knowledge can be brought on to a common basis of comparison. The logic of physics and the philosophical theory of knowledge may contribute mutually, each from its own meaning assignable to truthfulness, so that without achieving any finality as to the meaning of reality we may perhaps begin to recognize what kind of knowledge was that outlined in Part I.

The present chapter initiates such a programme by noting that the impasse left by the failure of materialism, and the failure also of Eddington's importation of the mental into the physical, has some resemblance to the impasse left by the inheritors of the Kant and Hegel tradition at the beginning of this century. Possible ways out of the latter impasse were pointed by the modern Realists, in this country Bertrand Russell, Whitehead, Broad, and others; although the genius of this phase of philosophy has shown itself to be critical rather than constructive, and little agreement is found between the large variety of its adherents, I shall try to show why I consider it of very great importance for our understanding of what is to be meant by the truth of scientific knowledge to-day.

The healthiest sign in the change of philosophical focus begun by the English Realists is their emphasis on the problem of Perception, and on the need for deciding the status of 'Sense-data' as basis of experience of any external world. The term 'sense-datum' or 'sensum' became prominent in the writings of that school, especially Bertrand Russell and Broad, between 1910 and 1930, as answer to the question, 'What is the nature of the Object that each individual unambiguously apprehends, when a collection of closely associated people is focusing attention upon that portion of their common experience which comprises sensations of touch, sight, etc.?' Uncritical common sense had answered that the Object for all those observers is unique and 'physical' or 'material'; but this answer is inadequate, since, for instance, the white square actually seen by one of the individuals becomes the green parallelogram seen by another of them if he is looking from some oblique direction and through coloured spectacles. It is obvious that any description of the so-called perceptual or physical object is result of complex inferences based upon synthesizing the various groups of sensations, together with intelligent exploitation of recollection and communication. Something more primitive is required as Object, and something more private to each individual; something more unambiguously true to that individual's experience rather than to any product of intellection such as the 'white CUBE'. For this white cube in the above example could only be inferred by collecting the 'white squares and coloured oblique shapes' from the separate individuals. The type of object fulfilling these requirements is the sense-datum or sensum, which is not in

the older meanings either a physical or a mental thing. For example, a sensum is the patch with definite colour and shape which differs from observer to observer as they change their situation or the optical circumstances of vision in the vicinity of the white cube.

The advantage of theories of Perception which treat sense-data seriously as the 'real object', is that the problem of Error and Truth is segregated and removed into that domain of argument which deals with the relation of sense-data to anything we like to call a more permanent or more physical object, and on the other hand their relation to a perceiving mind. For we all have direct acquaintance with sense-data; just as a man colour-blind does actually experience the sensation of his peculiar or favoured colour, and error only arises when his sense-data demand a different interpretation as to the further objects from which they are supposed to arise, compared with the interpretations of a normal man. The experience of sensation, of which the primary object is thus definable as the sense-datum, is therefore our first instance of knowledge by direct acquaintance, and can conveniently be treated independently of any views as to what might constitute any truthful knowledge achieved through inferences, descriptions, etc., with all their wider possibilities of ambiguity and error.

Recognition that the difficulties in the problem of Truth for simple perception can thus be shifted from the direct object to the explanation of the direct object, at once brings these Realist epistemologies into a position capable of illuminating that reached already for the infinitely more complex problem of truth in physical science, in Part I. I had there traced a sequence from the strictly unambiguous measurement and the abstraction and correlation of measurement, through stages of theoretical explanation which might be a mechanics or a geometry or a group calculus according to the particular phase of science; the problem of truth became a question of the communicability of such explanation, and did not arise at the direct experimental level. The logic outlined for physics had outgrown many hasty philosophies, by regarding with Heisenberg and Dirac and Eddington the 'structure of relationships' as what is important in such communicability, not the mechanical picture of 'things'. The epistemology developed by Russell, Broad, and others would make such an account of physics understandable as analogous to that of general knowledge, not

inconsistent with the less quantitative approach to experience via the psychology of common perception; each separates the domain of certainty and unambiguous acquaintance, in which the Object is the sensum or the experimental situation, from the domain of explanation and logical or psychological syntheses. In those syntheses alone arise the possibility of True and Erroneous distinction, both for physicist and for common percipient.

One feature of this essay is the suggestion that the criterion of coherent communication in the physicist's problem of truth is not entirely irrelevant to the philosopher's, while what has been found unknowable and unimportant in the philosophical problem may also liberate us from misleading and wasteful demands to know too much from our physics.

(II) RUSSELL'S THEORY OF PERSPECTIVES, AND THE EXTERNAL WORLD AS LOGICAL CONSTRUCTION

A very striking alternative, among the possible views as to how sense-data are related to an external world of objects, is Bertrand Russell's repeated assertion that the supposed Perceptual Object need logically be nothing more than the aggregate of all sense-data presented to all observers. I have here used the term 'perceptual' or 'perceived' object to denote what is postulated by crude common sense, rather than the term 'physical' object often used, to avoid confusion with the physical objects such as electrons and atoms which no one supposes to be directly perceived by the senses.

I shall compare Russell's abandonment of the primitive demand for some permanent perceptual object 'causing' all the sense-data, with the physicist's abandonment of causality on the part of conceptual objects such as electrons, electromagnetic fields, ethers, space-curvatures, etc.; philosophers might become interested in this comparison when belief in those conceptual objects as 'necessary causal agents' fades in favour of acknowledging only the functional dependences and structural relations which confer communicability as the mark of truth for scientific knowledge.

Take the instance in which a large number of observers all 'see and touch a collection of coloured shapes'. Considering all orienta-

tions, points of view, nearness and distance, varied illuminations, etc., the infinite shades of variety in the sense-data make an infinity of worlds, even when populated by a very few observers grouped about a very localized situation. This is the situation which uncritical philosophy would have termed the 'perceptual object causing those sense-data'. Each of those worlds is a possible one, whether anyone at that spot under that set of conditions is actually experiencing it or not, so each aspect of the universe seems independent of any particular mind and constitutes an external reality which is not itself mental. In this way Russell cuts away much of the tangled controversy between (a) an Idealism postulating things perceived as only existing in the percipient's mind, and (b) an older and cruder Realism postulating material or physical things external to the mind but of whose existence it seemed eternally impossible to obtain independent confirmation since we only 'know' the sense-data. His external world of objects just is the sum total of all the sense-data which would be presented if all possible observers' situations were collected: from the analogy of optics, where in a particular type of sensation the change of viewpoint changes even slightly the experience, Russell calls the 'view of the world' actual or possible to any situation a 'perspective'. Each perspective is occupied by a set of sense-data peculiar to itself, different from those characterizing every other perspective. Adjacent perspectives will contain sets of sense-data not very different though never identical, so that correlation can be (and for coherent knowledge must be) established between any two or more adjacent sets. One way of speaking of this system of correlation is to postulate an identical supposed 'physical object' underlying all sense-data: but the causal relation is not essential here any more than in physics, provided the correlation is secured. The status of this physical or perceptual object, introduced to explain our correlating, is that of logical construct. An important task in future philosophy will be to discover how much imagination is used in such a logical construct.

Reference back to the later chapters of Part I will recall how very analogous to such argument was the contention that in modern physics our work is to correlate measurements and to seek for functional relationships providing the communicability of scientific knowledge. The supposed underlying 'thing', whether

'matter' or 'electromagnetic field', was no more than a logical construction too, for explaining the correlations.

It is possible that comparison with some of the alternatives in the most general epistemology of the process of Perception might have relieved the scientific world of its shock at finding its supposed 'thing' dissolving into Eddington's 'structure', or into Heisenberg's or Dirac's patterns of abstract groups and undetermined symbols.

But it was coherence between such logical constructs, embodied in communicable propositions and equations, which conferred titles to truth upon any physical theory in the conclusion of Part I, and this coherence is a term also to be given connection with a general epistemology—but a very different one—in chapter eight. Meanwhile the available alternative to Russell's drastic elimination of perceptual objects must be noticed, to see whether it could possibly spoil the analogy with the situation of physics.

(III) BROAD AND THE EXTERNAL OBJECT OF PERCEPTION; STATUS OF WHITEHEAD'S PERCEPTUAL OBJECT AND SCIENTIFIC OBJECT

The obvious possibility, less startlingly agnostic than Russell's suggestion about the supposed world of common sense, is that we do possess means of proving that perceptual objects exist as independent entities apart from their status as aggregating all perspectives among the sense-data. C. D. Broad has marshalled the evidence exhaustively in *The Mind and Its Place in Nature*, and with vastly profounder consideration of psychological factors than employed by the purely logical Russell. He does decide tentatively in favour of the common-sense assertion that we have right to our belief in the independent perceptual world. But the borderline between introducing the latter by act of faith and by 'considerable probability on evidence' is very shadowy, and most scientific and philosophical opinion undoubtedly only agrees with common sense by leaping a gap in the proof which it is healthy for us to admit.

Broad's elaboration of argument does not diminish but rather enhances our comparison with the logical status of physics in Part I. Whether Russell's suggestion (which I do not know if he still maintains) is in the end to be accepted or rejected, there is obviously a

degree of reality to be accorded to sense-data similar to that accorded to experimental facts in physics, and both have direct claim to be above the possibility of untruthfulness. The supposed Perceptual Object requires on the other hand an enormous train of mental activity to establish even its probable existence; it readily descends under critical analysis to the important but inaccessible status accorded to atoms, electrons, etc. Not that the latter are presumed to correlate direct perceptions, but their justification like that of the perceptual object is their convenience for correlating experience or the more complex products of experience.

It is worth noticing here that Eddington's 'knowledge is only of structures, not of things' is closely parallel to Russell's 'All aspects of the Thing are real, whereas the Thing itself is a mere logical construction'; although Russell and Eddington would disagree radically as to the share of the observer's activity in responsibility for the form of the construct. Both dicta may apply to the 'thing' which common sense says underlies every ordinary unsophisticated perception, and also to the 'thing' which a more sophisticated scientist says underlies the more elaborate and precisely controlled perceptions of atomic and electrical physics.

Since something like an act of faith is more often employed by all of us than a rigorous proof, those who fear lest 'logical construct' will be stigmatized as 'myth' may feel that there is more than healthy humility in our agnosticism over physical objects; if they find an uncomfortable deficiency in the shadowy ghost of an external world retained by the Russell theory, they may be comforted by Broad's laborious erecting of the probability of its continued existence. But if so, they must recollect that the main argument for the latter is just the fact that differing percipients are in sufficiently close agreement to avoid chaos. Such agreement is no other than the 'communicability' by which was hall-marked 'true' scientific knowledge; if the existence of the electron is predicated in true propositions in this sense that they are communicable, and only in this sense, then the correlating of sense-data in adjacent perspectives confers a somewhat similar range in degrees of truth upon any statements that permanent objects of direct perception do exist. Broad's addition to Russell's mythical external world seems in this way an act of appeasement to emotional satisfaction, rather than a confirmation of our unprovable faith that 'something out

there survives our wandering attention'. The difference between these two philosophers is again that Broad is interested in other than purely logical aspects of the human mind, and yet is not captivated by the Kantian dominance of a subjective factor with which Eddington fills out the emptiness of a world containing only 'logical constructs'. Both Broad and Russell, however, enforce this useful answer to the common-sense complaint that physicists cannot prove that electrons, etc., exist, 'Neither can any of us prove that any permanent perceptual objects exist'.

An intriguing superposition of two very different approaches to the problem of 'What is truly known in science?' would be to rewrite the hierarchy of Whitehead's 'percipient', 'perceptual object', 'scientific object', in terms of these views that all but the sense-data themselves are logical constructs or Forms conferring degrees of truth by rendering individual perspectives communicable. Scientific object and perceptual object might share common status in a way not expected by the early admirers of Whitehead, and the latter's beautiful geometrical picture of transitions from percept to concept would be shorn of the metaphysical weight attributed to it by many. I have already suggested (Part I, chapter 4 (I)) that Whitehead's important work now needs rewriting with Milne's addition of the unique status of Time, but it can now be further enriched with Eddington's emphasis on the status of Form and Structure and with Russell's elimination of unnecessary entities in the process of Perception. Without such unification by superposing theories so different in the meanings which they give to common notions, we are left with a disturbing doubt of whether to accord any metaphysical significance at all to 'scientific object'. If electrons, etc., share with every common object of perception their reduction to being Forms not Things, our ultimate concepts of science are likely to infect the entire world around us, with their property of being useful conventions but in the final analysis unknowable. Perhaps only imaginatively can we attempt to grasp what we are left with. Lest we decide that the only possible metaphysics of the future is the universal scepticism of Hume's type, or the idealism of a Berkeley to whom only minds and ideas are real, a few tentative remarks are here appended, as to the possible character of what can ever be truthfully known about the external world.

PERCEPTION OF THE EXTERNAL WORLD
(IV) LEGITIMATE PHILOSOPHICAL SUGGESTIONS FROM THE SCIENTIFIC LIMIT OF WHAT CAN BE KNOWN AS TRUE

There seem to me to be two alternative but allied philosophical conclusions, from this emergence of 'perspectives' or 'groups of relationships' as the irreducible which must replace the 'perceptual object' of the epistemologist as irresistibly as it replaces the material or electrical or etherial 'thing' of the early physicist. (a) We might suppose that an abstract form or structure of relations between logical terms is what we are ultimately to become capable of apprehending, instead of any substance; or (b) we might make the corresponding psychological (or even sociological) supposition that knowledge is ultimately an affair of putting into order our communications with each other. In the latter case the linking together of individual entities which are intelligences is what constitutes both the process of knowing and the thing known.

Each of these types of metaphysics would preserve the essential 'structure rather than things'; but the one stresses knowledge while the other stresses knowers. There is one feature common to both these ways of regarding the conclusions of Part I on physics and the conclusions of Part II on perceptual objects as logical aggregates of sense-data; namely that the analysis both of ordinary knowledge and of that specialized kind called science agree in revealing a universe whose character of reality is the possessing and exhibiting of 'Pattern'. The pattern in the first of our metaphysical alternatives is the most abstract, the pattern surviving when things material or physical or mental have been explained away and the bare framework remains only of how symbols can link into groups. This would be perhaps Sir James Jeans's famous universe of the mathematical properties. The pattern in the second alternative is more humanly an ordering of the relations between receptive individuals having something of the character of minds. The two terms used in Part I as criteria of truth, Coherence and Communicability, belong respectively to these alternatives (a) and (b), since they focus attention on the logical and the psychological aspects of truth in turn.

It is perhaps easier at this stage to see how Eddington's discovery, that structures themselves mean more than the terms they bind, misled him into the Kantian view of minds imposing upon the

world the form it has to exhibit. He was surely unconsciously attempting to respond to the needs of these two alternative kinds of metaphysics simultaneously. They may be two sides of the same story, but great care must be taken if the two become superposed.

Actually there seems no decisive ground whatever for assuming that a correct metaphysics must postulate only a network of abstract logical relationship, or a society of intelligences exchanging communication; either universe would be ruled by the definition of scientific truth as coherent fitting of quantitative functional relations, and would present our experience of perception as Russell's perspectives. Correlation instead of isolated facts is the essential meaning of knowledge in each case. Perhaps the duality between a philosophy whose ultimate entities are abstract Forms, and a philosophy whose ultimate entities are intercommunicating recorders, denotes two finally irreducible ways of regarding those facts which enforced our definition of scientific truth in Part I. The argument of Part II so far shows how much wider the notions of communicability are than the particular domain of physical science, and how our entire experience of an external world may depend on them.

(V) 'EXTERNALIZED' NATURE AS ESSENTIAL TO SCIENTIFIC METHOD AND AS PROVIDING THE RELIABILITY AND LIMITATION OF ITS PHILOSOPHY

But if the Realistic pursuit of the problem of Perception leads thus to a theory of knowledge and test of truth somewhat similar to that required by the abstractions of recent physics, we reach a stage where a sharper distinction must be drawn between the treatment of knowledge in science and in the most general analysis of experience. This distinction has been foreshadowed at several points in Part I, but can only now be seen at its greatest significance, since the intervening chapters of Part II have ceased to ignore completely the Subjective aspects of experience.

Eddington failed at this stage, because he introduced the Subjective into physical discussion on grounds of a fallacious inference from his own ability to predict rationally some empirically checked figures: Kant failed at the same stage, because of fallacious infer-

ence from the antinomies of Time and Space: Alexander failed, as did the materialists, because they all included the mental and the physical under a single 'substance'. Such failures are examples of inadequate superposing of the Subjective or Internal world of the mind upon the Objective or External world of 'Nature'.

It is therefore a dangerous discovery that we have now reached; for if knowledge is resolvable into patterns of relationships, whether it be the knowledge called science or the commonest perceptual knowledge, we have decided that this apprehending of Forms might be regarded either as evidence that the universe is a network of abstract structure whose relata are unknowable, or, alternatively, as evidence that the universe is a community of recording minds. The same criteria of truth apply to both. There seemed, so far as metaphysics is concerned, no clue as to which, the abstract or the personal, was likely to be the more lasting picture. But, in the case of science and the philosophy of science, the decision is not so open: the most general of metaphysical systems may derive from logical or from psychological data, indeed must comprehend both and far more, including the intensely personal data of the artist's and moralist's experience, whereas science and the analysis of scientific knowledge must always confine their attention strictly to an external or an artificially 'externalized' universe of Nature. Otherwise science loses at once the source of its impersonal reliability and trustworthiness, its truth based upon quantitative communicability. This is where it seems that Eddington passed unconsciously from good logic (in the structural aspects of his theory) to bad metaphysics (in the subjective aspects), while believing that he was still arguing as physicist and invoking physical criteria.

As consequence of this vital distinction, which eternally confines physics to ignoring the physicist himself, communicability and coherence in the scientific criterion of truth imply solely the exchange of impersonal measurement data and the comparison of the propositions embodying their functional relations. The observer or calculator is not to be a complete human being, but the abstraction of one portion of a human being's powers. He might well be an automaton recorder possessed of the capability of detached analysis. The reason, in the end, why we distrust Kant's or Eddington's invocation of a controlling mind among scientific data, to extract from the world the Forms which the mind im-

posed, is that at some stage this mind cannot be entirely acquitted of aesthetic or ethical preference in its treatment of its observations. Once it steps beyond the automatic recording of the pattern of time-signals, etc., the physical phenomena would cease to be rigidly communicable and physical theories would thereby cease to be able to sustain any claim to truth in the sense of our definitions.

The universe of the physicist's discourse is therefore essentially a closed Nature: even if he be promoted some day to investigate the human brain and nervous system, the latter must be seen under the necessary guise of an objective abstraction into which the intrusion of the Subjective, with its preferences and prejudices, cannot be permitted.

It is this artificial character of a Nature made to be external and exclusive of its discoverers, which finally rules out all Kantian theories from philosophy of science, and also in the opposite direction rules out physical concepts from alone deciding any metaphysical view of human destiny. It confirms not unexpectedly the inadequacy of materialism and the other philosophies analysed in Chapter 6.

Since not only Kantian but other Idealist philosophies are bound to comprehend the Subjective aspects of experience as much as the Objective, whereas Realism is easily adaptable to a precise account of the objective world and has not been very adequate to the subjective, it would be patently foolhardy to utilize the notion of Coherence without further explanation at this point. For the theory of truth as 'coherence', which I have several times already invoked, has usually been considered a monopoly of the Idealists. The provisional and not too closely circumscribed use which I have made of the notion of 'truth as coherence' must now be tracked down to its philosophical environment; it will be necessary to ensure that the importation from thinkers who have notoriously been more preoccupied with the Internal world of Mind does not vitiate our present ruling that Mind is the one topic irrelevant to the scientific truthfulness of accounts of a closed External Nature.

Chapter 8

COHERENCE THEORIES OF TRUTH AND THEIR INDEPENDENCE OF IDEALIST METAPHYSICS

One reason why a modern Realist account of Perception provided so readily a parallel to the notions from which evolved a physicist's definition of truth, was its facility for closing the external world and ignoring the subjective mind. Some Realists in fact can regard without inconsistency a mind as simply a percipient focus for incoming impressions; this is allowable for physics, and fits a philosophy of science as psychological parallel to Russell's theory of the perceptual object. Indeed, in many varieties of modern Realism, the subject 'mind' is no more than the logical construction—often stigmatized as 'myth'—to which the perceived object was already reducible. Any metaphysics, necessarily having more to account for than the isolated aspect of mind called perception, may well have to add more to the myth of the mind than to the myth of the physical world. Already, by evoking in Part I the notion of Coherence as a test of truth within the physicist's logic, we are forcibly brought into contact with the Idealist schools which have not had the weakness of ignoring the other aspects of mind. Indeed, Idealists have generally suffered from the opposite defects compared with Realists, and tended to treat the Subjective, or the internal world of the knower, far more seriously than they were prepared to treat the external world of the known. In our present concern, the possible contribution of Idealist traditions is to be sought, not to any metaphysics of the external world, but to a criterion of truthfulness which may serve science and philosophy of science without intruding, as Kant did, his subjective control over our closed external Nature.

Truth has often been taken as definable either by self-consistency and internal coherence of some set of ideas, or by the correspondence of those ideas with independent facts. Idealist and Realist

schools have stressed these two alternatives respectively. I have been utilizing Realist notions hitherto, but the Idealist definition must be scrutinized for use. Need Coherence and Correspondence here imply all the associations which they have carried in general philosophy? It ought to be possible to detach them from the metaphysics which has hitherto been held suspended between two unanswerable difficulties: (a) 'Coherence, being a property of ideas, is only a valid test of truth if we suppose nothing but ideas exist.' (b) 'Truth as correspondence between idea and external-world is impossible to establish, because there is no separate check on that world save by comparing idea with another idea.'

But in Part I, 'coherence' meant coherence between scientific propositions; similarly 'correspondence' would have meant correspondence between the proposition which was a recording of a measurement and the proposition which synthesized an abstracted set of all the measurements, at one stage in physics, and at another stage it would have to be stretched to mean correspondence between the synthesis and the explanation. This treatment of coherence might include, therefore, in such limited use of the term the actual fact of correspondence, without demanding a separate world from that of propositions. Since coherence was found useful as describing the stages in communicability which defined the physicist's truth, it can in this restricted usage avoid the conflict between metaphysical implications of the traditional Idealist and Realist uses of the word. The precise nature of the restrictions, and the useful possibilities, in transferring a coherence theory of truth from idealism into scientific philosophy, may be clarified by the following brief account of how such a theory has served those philosophies which have concentrated upon 'a world of ideas'.

Coherence between ideas is a criterion of truth evolved in the particular treatment of knowledge and reality which is traceable back to Plato, and was prominent in the philosophies derived from Hegel's extension of Kant's subjectivism. The modern Oxford logicians, Bradley and Bosanquet and Joachim especially, have evolved the most detailed expression of this way of defining truth. Their voice in recent philosophical circles has not been so strong as it was a generation ago, and tends to be drowned by that of the Realists; this is partly because their deductive systems are not so obviously adaptable to the scientific problems of the twentieth

century, though their intellectual ancestor Plato knew some things which the most modern physics in its abstraction is beginning to rediscover. It is obvious that the novelty of contact between these idealisms and current philosophy of science, if not to fall under the objections brought against Kant and Eddington, will only be safe if we can see where idealist CRITERIA of knowledge do or do not depend for validity upon some metaphysical doctrine as to what exists to be known and what exists to be the knower. Historically, the coherence theory of Bradley and the others was a consequence of deciding that the universe is explainable as consisting of mental or spiritual entities solely—an even more radical interference with the prejudices of common sense and of physics than Eddington's superposition of mentally created Forms upon a world of Substance. There has always been a wide variety of such theories, and the ultimate sanction common to them all is perhaps the acknowledged fact that our most direct acquaintance is with events localized in our individual consciousness. If what we are directly aware of is a set of facts which involve at any rate our own mind, there is at least the intriguing possibility that the world might be explainable without postulating the existence of anything whatever save ideas, or the content of one or more minds.

Idealism, or 'mentalism' in this sense, is divisible into alternative schools according to the number and variety of separate minds, one or many, postulated by any theory, and according as any non-mental entity is completely non-existent or is allowed somewhat grudgingly a subsidiary role in the economy of the universe. Plato, to whose notions the fondness of recent physicists for abstract symbolic forms bears a remarkable likeness, considered that knowledge of particular 'things' attained through sense-perception is a degraded species of mere opinion; from such, he considered that philosophy alone liberates us to know the Ideas or Forms which are the only Reality and of which the particulars are incomplete and sometimes misleading copies. A world in which Ideas are real and so are Minds, but from which external objects are eliminated, also characterizes the Subjective Idealism associated most strikingly with the work of Berkeley: for him the whole universe can have no being except as an Idea in some mind, the mind of the deity if not of one of us. Carried to extreme, theories denying any external counterpart of the ideas internal to

our minds can easily be pushed into Solipsism, or a notion that nothing exists save the percipient himself. Though not susceptible of logical refutation, solipsism is still less likely than Berkleyan Idealism to commend itself to common sense, but it is a useful reminder that theories may be at the same time irrefutable but quite unconvincing.

The impasse in the accompanying theories of knowledge, leading to Kant's metaphysics of Forms of Intuition which was called an idealism for entirely different reason, was noticed briefly in Chapter 6 (III); but it is in the Hegelian overdevelopments of Kant's impulse towards subjectivism that Idealism tends to freeze into a spiritual Monism. This monism postulated a hierarchy of existents purely mental, whose ultimate unity was expressed as an unattainable limit, unknowable but omnipresent, the 'Absolute' or all-inclusive Idea to which alone the full title of Reality is assigned. Revolts from this theory, allowing Pluralism or the recognition that the universe is not One but a multiple of individuals, were worked out by Idealists who began as Hegelians, notably McTaggart, and by others such as James Ward who derived also from the universe of sentient but rudimentary atomic 'minds' postulated centuries before by Leibniz.

It is unlikely that such metaphysics, in their wide diversity all agreeing to despise or even deny the existence of non-mental constituents of reality, will succeed in providing very convincing explanation of the world of external Nature necessary to physics. Perhaps a completely spiritual universe, in which even 'matter' was nothing beyond some manifestation of mind, is slightly less repugnant to scientific temper than the Kant-Eddington world in which mind interferes but is not the sole constituent; but neither type of idealism is likely to offer to physicists more than the aesthetic and unprovable imagery which colours many attempts to see the universe whole, and which had also been the principle merit of materialism and of Alexander's universe of Space-Time.

Now it is in certain of these Idealisms, particularly the Hegelian system for which Reality is an all-embracing unity or 'The Absolute' into which known and knower alike are engulfed, that the view of truth as meaning 'coherence between ideas' became popular. It is easy to see, from even our briefest summary here, that coherence is not merely a convenient test of truth but its only

possible way of being defined, in such a philosophy. It is the natural and inevitable outcome of regarding 'idea' or some such mental term as characteristic of the whole of reality. The dualism of two worlds, postulated if truth is 'correspondence' between internal thought and external thing 'thought about', is avoided by these idealisms, though we must notice that some forms of Realism escape more complicatedly the difficulties of that dualism. Clearly it is an advantage to regard Subject and Object as mere partial abstractions from a real whole or unity transcending both, even at the expense of erecting an Absolute that no one has ever been able to understand.

It should, from these considerations, be possible to see that our definition of truth as coherence between propositions, including as it does the fact that coherent statements do 'correspond' to one another as any Realist would want them to correspond to their facts, is in no way dependent upon any theory that nothing save ideas can exist. The recent tendency of physics towards abstract relationships and logical structures demands tests of validity which are inevitably tests of how these structures cohere and are self-consistent. Even the Realist view of the world of perceptual objects, as a world of logical constructs, might well impose a similar coherence test or even a definition of truth in terms of coherence among those constructs, if Realists had not been prejudiced against a word associated with the Idealist's metaphysics and especially with his mystical terminology of The Absolute. Coherence theories were indeed necessary to the Idealist, but Idealist postulates as to what the world consists of are not at all necessary to the useful notion that coherent propositions are our only guarantee of truth in science, and perhaps in epistemology.

Two warnings only seem to me needed, in a plan of divorcing the coherence theory of truth from a metaphysics of Absolute Monism. (a) A coherence test is of whether a set of statements is self-consistent or contains inherent contradictions: but this test ought to be regarded first of all as offering criticism of the particular logician's skill at formulating those statements, not solely as deciding that the underlying notions are mere nonsense. I have emphasized in Chapter 6 how very far astray philosophy was led by the Idealist treatment of the antinomies, or inconsistencies in formulating temporal and spatial relations, which misled Kant,

Hegel, and Bradley into denying all temporal and spatial reality. The modern mathematical logicians having improved the formulation of the relevant propositions, the antinomies no longer puzzle the expert, but is that to mean that the supposed non-reality of Time and Space has been turned into reality? Lack of self-consistency of a set of propositions, when the coherence test proves negative, does not necessarily confer unreality, but may instead call for technical skill of logicians to remedy their defects in the art of definition.

(b) When the test of a set of propositions by their coherence proves positive, and they seem to be formulated without detectable mutual contradiction, the philosopher must not thereby claim that they constitute the whole truth or the only truth. Actually, the Idealists covered themselves against this error, by saying that not until we comprehended The Absolute would any separate constituent idea be completely valid. In a philosophy of science we may well learn caution from physics itself: we are used there, by now, to recognize that more than one self-consistent explanation may coexist, for instance the wave-theory and the particle-theory both simultaneously applicable to limited aspects of the nature of electrons and the nature of radiation. Each is 'truthful' by a coherence test, within the domain in which the appropriate concepts have experimental significance. The caution is worthy of extension—in very few arguments is one theory 'right and therefore all others wrong'.

With these warnings observed, there remains no reason why the notion of coherence should not be freed from idealist metaphysics and made useful in philosophy of science, as it is in practice within physics. A terminology of 'coherence between propositions' is preferable to 'coherence between ideas' or even 'between judgments', and will avoid the old associations; it can next be incorporated in a more systematic summary of the epistemological implications of science from these last two chapters.

Chapter 9

REALIST TREATMENT OF PERCEPTION AND COHERENCE TEST OF TRUTH AS BOTH NECESSARY TO A PHILOSOPHY OF SCIENCE

1

It may now be possible, on the basis provided by Chapters 6, 7, 8, to systematize the tentative answers to problems inherited from Part I, where Truth in physical science was a coherence between functional dependences rendering communicable the structure of relations observed between measurable and especially Temporal quantities. Grounds have appeared in the subsequent argument, for assessing what kind of a world it is, concerning which science thus claims to be offering such truthful explanation, and why both Realist epistemology and a Coherence borrowed from Idealist epistemology can each contribute to its intelligibility. If, as suggested in Chapter 7, it is possible that such explanations have parallels in philosophical theories adequate to describing the world of common unanalysed perception, we shall still have to ask finally how is such truth related to our judgments about any other world; for we have omitted from the philosophy of science all judgments denoting aesthetic or moral value, the qualitative instead of the quantitative. Do the theories of knowledge suggested in recent philosophy Idealist or Realist, reinforce in a wider domain or restrict to the narrowest the criteria which evolve from the particular aspect of experience met in physics? In Chapter 10 some relations of quantitative to qualitative judgment are discussed, and in the present chapter the mutual contribution of physics and of the Realist–Idealist antithesis is suggested, involving our somewhat unorthodox synthesis of apparent incompatibilities on the simpler territory of neutral physics. The physical logic of Chapter 5 of Part I may clarify the topics of Chapters 7 and 8 of

Part II, while the latter in turn might well offer illuminating comment on the former.

2

One significant feature can be extracted at once, as common to (a) all the 'object' conceptions which physics has transiently utilized as possible 'bricks of the universe', and (b) whatever 'thing' or 'origin of sense-data' that Realist theories of Perception may postulate. All these plausible constituents of an external world, whether of the specialized and precisely defined world of the physicist or the common-to-all world of everyone's perceptions, NEED be only logical constructions: proof of their independent existence as objects or any kind of substance is at least very dubious. Electrons and electromagnetic fields, even space-curvatures, are real enough in physics, but their reality has a specific and not necessarily the traditional meaning. They were shown in Part I to have the status of devices serving to render communicable the functional dependences into which observed regularities of measurement can be fitted when treated by the appropriate mathematical transformations. More elaborate conceptual objects, as far back as ethers and vortex atoms, and including since then the Rutherford-Bohr planetary atomic systems, and to-day the Shrödinger wave trains and the Heisenberg-Dirac matrices and abstract symbols obeying only Group properties, are all of the same epistemological status as electrons and electromagnetic fields. They are justified as contributing to Truthfulness in science by their use in extracting the essential logical relationships over an increasing variety of measured observables. I emphasized sufficiently, in Part I, the disasters to progress of physics which arose from supposing that any one of these conceptual objects ever represented final decision on 'what the universe is made of'. That type of erroneous supposition also gave rise to the uncritical materialisms deplored in Chapter 6.

Common ground between such logic of physics and a possible epistemology of Perception appeared, when the similar relabelling occurred from 'underlying stuff' to 'logical construction collecting the perspectives'. This was one of the arguable theories whereby Realist philosophers following Bertrand Russell could eliminate the

crudely demanded world of permanent external objects as cause for all the transient sense-data which we experience. Here was only one of the possible varieties of recent Realism, and other philosophers have preferred to retain the existence of a more commonsense world, in spite of the almost insuperable difficulty of imagining how we obtain and check our knowledge of such a thing. My brief mention of Broad's alternative served to show that knowledge of what 'things' underlie sense-data is at best hard to establish and persistently mocking of our complacent assumptions that the nature of the external world is obvious. Russell's elimination of the external object is a patent demonstration that about the most familiar of experience we are sometimes forced to be very agnostic in interpretation; so the agnosticism of the physicist concerning his ultimate concepts ought not now to be shocking or even unexpected. It must also be remembered that the elimination of the perceptual object (and occasionally of the percipient mind too) was one phase only of Russell's intellectual pilgrimage: we all know the remark 'What Mr. Russell thinks to-day the rest of the philosophical world will think to-morrow but by then Mr. Russell will have gone on to think something quite different.' The particular doctrine which I have been using, expounded in his *Knowledge of the External World*, *Analysis of Matter* and *Outline of Philosophy*, and greeted with the usual mixed scandal and exhilaration, may not be seriously held to-day: I am using it as an example of what is rational, not necessarily as what is finally valid. It seems to me exceedingly important as showing that commonly accepted worlds, physical or otherwise, are by no means indispensable to a perfectly adequate account covering at least the objective side of experience; those worlds are logical constructs, whether an accompanying metaphysics decides to postulate a community of intellects or to leave a network of abstract relatedness as the final contents of the universe.

Taken with this caution, Russell's suggestion is that 'physical object' is no more than the aggregate of the perspectives into which all possible sense-data can be grouped; and it offers a valuable clue to future philosophy of physics. The features common with the abstracted character of modern atomic science, preoccupied with relations between undetermined symbols, indicate that a Realist analysis of Perception and a purely physical analysis of 'Nature'

are agreed in complete agnosticism as to what (if anything) CORRESPONDS TO our logical patterns of equations or of sense-data. 'Reality' shifts to some characteristic of the grouping of relations between certain kinds of Temporal experiences, and need no more be attached as label to 'things'. It is a Realist, not an Idealist, philosophy, which in the end vindicates Eddington's dictum that structures and not things are what we come to know, though the test of truth thereby comes to resemble more the Idealist's Coherence than the Realist's Correspondence.

We here approach solution of the old problem of according a status to Whitehead's Scientific Object (Chapter 4 (I)), which thus becomes nothing so radically or qualitatively different from his Perceptual Object, while for purposes of a philosophy of science alone a Percipient Object could readily fall into the same category of logical construct. Within a philosophy of science there is no need to postulate underlying material or mental factor to explain further the logical structures which are knowledge.

3

Physics in its turn can contribute a negative but extremely valuable clarification to the implications of modern Realist philosophy. The rapidly altering fashions in the ultimate concepts of physical science have taught us to outgrow the arrogance which might demand that they cover also the facts of the subjective aspects of experience. 'Mind', as the subject aware of aesthetic and ethical Values, could, with some stretching, be pictured as describable in terms of the Victorian's 'matter'; but now that a daily altering set of logical relationships is all that we find we know in truth, we have become healthily agnostic and content to leave those aspects of experience not amenable to physics. They enjoy their own meaning of 'reality'.

Alexander's universe of space-time would have been wiser not to include the facts of personality, which, as with the universe of the old materialist, it was framed in too physical a language to grasp. Eddington's inversion of the error by importing mind into physics was even more disastrous than a complete Idealist's submergence of physics beneath the mental. The more rapidly we now advance from the solid atom of the materialist and the elastic ethers to the

abstract wave-like variables of Dirac's and Heisenberg's equations, the less likely we are to be tempted into seeing the physicist's own mind and whole personality 'explained' in a language which is not built even to describe it. Even the language of the artist or poet is inadequate enough to the terror and joy it has to communicate, and the modern physicist has learnt from his theory of knowledge and truth not to pretend to territory over which his epistemology has no jurisdiction.

Just as no physicist to-day would say 'aesthetic and moral judgments are nonsense because they are not expressible in wave functions', so the camp-followers of Realist philosophers would do well to learn from this, and to restrain their arrogance from thinking that personality vanishes when perception is fully described by Russell's perspectives. The latter merely are not the language for encompassing all the judgments to be made by the percipient, who is conveniently but not ultimately a mere focal point in the imaginary spatial distribution of the perspectives, so far as physics and Realist logic are concerned.

This contribution from physics, warning the philosopher against an over-comprehensiveness which physicists have mostly outgrown, could be summed up in the argument of Chapter 7 (V). Physical conversation is essentially bound by its definitions of knowledge and truth to an external or even an artificially externalized Nature; the very feature of greatest use in the Realist treatment of the problems of Perception binds this philosophy to something very like the physicist's limitation. The Kantian intrusion of the Subjective was a contravention of this essential limit, and its failure serves to emphasize that neither physical analysis nor the logical analysis of common perceptual experience has need or authority to produce a metaphysics embracing the Subjective as well as these abstracted pictures of the Objective. It is the Objective world which is so successfully treated in terms of logical constructs, and the Subjective ONLY in so far as it can be traced to the focal point which receives and records. But there are topics beyond that automaton recorder; physics and Realist logic alike are bound to ignore the physicist and the logician together with the judgments that these personalities indulge in outside their technical job.

4

The adequacy of a set of logical constructions is necessarily assessed by their coherence or mutual consistence. The notion of coherence, firstly as this useful empirical test of the structure of scientific relationships and equations, turns out therefore to be a valuable importation from a very different philosophical school than the Realist. But truth as coherence between the propositions of logic or physics has not the metaphysical implications which accompanied the theory of coherence between ideas in a universe consisting of nothing else. In Chapter 8 suggestions were made for segregating this view of truth as a practical test, and even as a useful definition, away from the Idealist metaphysics in which it arose and to which it was necessary.

The possibility of thus utilizing outside the Idealist philosophy a valuable item from its logic, returns us to the fundamental ambiguity which a view of truth as communicability had imposed from our Part I. Coherence was a test of this communicability in scientific truth, and coherence between 'ideas' was scientifically but not metaphysically identical with our coherence of 'propositions and relations expressible as equations'. Whether Form is the only reality (a curiously modern Platonism) or whether the universe is a community of intelligences, is a question outside scientific jurisdiction to solve: the notion of coherence, extracted by physics as a contribution from Idealism more lasting than Hegelianism, can be applied indifferently to either alternative of this most insoluble ambiguity. Truth as coherence, either between ideas in a world of minds or as coherence between propositions in a world of logical form, has always the advantage over its old rival of 'truth as correspondence'; it avoids the infinite regress in which we had to ask: 'By what independent comparison have we any check on this supposed reality with which our statements must correspond?' There is surely a most healthy agnosticism concerning the stuff of the universe, shared by physicists and Realists, that makes each adopt the coherence theory of truth as soon as they abandon the claim to know all about the unknowable 'thing'.

5

Mutual influence between the logic of recent physical reasoning and the epistemologies of Realist and Idealist is not, therefore, unfairly one-sided. The need for the coherence test of truth is imposed not by any metaphysical theory of the nature of things, but by the growingly abstract character of the propositions used in physics. This adaptation of a feature from the Idealist logic is therefore divorced entirely from the latter's Hegelianism. On the other hand, Russell's demonstration that the Perceptual Object need not be any 'thing' beyond the grouping of sense-data is so like that reduction of the physicist's world to 'structure of relations' that epistemological Realism and modern physics can readily share many of each other's powers and limitations. In particular the recognition that there are topics of importance arising from genuine experience, but not susceptible of treatment in the quantitative science of physics, suggests that Realist epistemologies have no title to discuss adequately those aspects of personality other than the recording and synthesizing of sense-data.

The net gains are twofold. (a) There is a satisfactory chance of putting the physical sciences on to a clear basis as regards the meaning of knowledge and truth in their accounts of the EXTERNAL world. They are absolved from need or responsibility of providing any view which is to synthesize the INTERNAL world of mind with that of the closed Nature they demand. (b) Outside the scope of physics and also of the Realist methods in epistemology, there must always be recognized the claim to reality of those judgments of Values, for instance aesthetic or ethical, in which the truth criteria of quantitative and logical symbolisms cease to retain the original meaning.

Some prolegomena towards comparing with the scientific those alterations of meaning, when the Subjective is no longer an abstracted focus of perspectives or automaton recorder, will be appended in the final Chapter 10 as a Part III distinct from our main problem but suggested by the latter as sequel.

SUMMARY OF CONCLUSIONS OF PART II

Part I had led to a view of physics as emerging from its early stages a pursuit of causal mechanisms, and later as exemplifying with the work of Heisenberg, Dirac, Eddington, Milne, a growth of functional dependences to whose symbols no 'known thing' need be attached. The validity of such logical structure had been discussed in terms of a criterion of 'truthful explanation of Nature' involving the communicability and coherence of relationships embodying observable quantities.

In Part II, these decisions from Part I, concerning the kind of reasoning now current in physics and the meaning they confer on scientific truthfulness, are compared with philosophic treatments of what 'knowledge' has meant to some Realist and Idealist schools of opinion. In particular, the Realist treatment of Perception and the Idealist conception of 'coherence', if dissociated from metaphysical theories which they have sometimes been held to imply, can both be seen to be exemplified in the modern logic of physics. The power and the limitation of the latter in turn indicates how far theories of knowledge can be extended without depending upon unprovable theories of existence and reality, and what aspects of experience would have to be included beyond those scientifically describable before adequate philosophical interpretation of the whole of experience were attained.

CHAPTER 6. Two quite different attitudes to Eddington's philosophical physics here emerge. (a) His view that 'knowledge is of structure, not of things' was a valued clue throughout the advance beyond causal mechanism in Part I to our 'truth as coherent communicability of logical Forms' in the Dirac–Heisenberg era. (b) But in the wider philosophy of the problem, in Part II, Eddington's Kantian imposition of a mental factor for creating the physical

forms was rejected, as allowing one abstracted concept to dominate another and control the whole objective world of experience. This would always be fallacious, whether that concept were mental or material. So the error is common also to all materialisms, and also to Alexander's treatment of Space-Time as if it were a 'substance'. No single term, with material or mental or geometrical connotation has shown itself able to be extracted from the context of its particular aspect of experience and made to explain all other aspects.

Chapter 7. Failure of physically based metaphysics bears some resemblance to the impasse at the end of the Hegelian era, and suggests seeking relevance in the modern Realist's solutions to the philosophical problem of 'what underlies Perception?'. Russell's early theory, that the external object previously supposed to be assignable as cause of sense-data need only be a logical construction, correlating the aggregate of individual perspectives, was found to be suggestively analogous to the most modern abstract physics; for in the latter the 'object', electronic or other, was strictly the aggregate of observables capable of being symbolized in equations whose terms are not to be interrogated for 'meaning'.

The very circumscribed alternatives left by Russell's theory of Perception, and even Broad's less iconoclastic revision, allow Whitehead's 'scientific object' and Milne's 'structure correlating temporal experience' to present to the philosophy of science a universe of two alternatives. It may be either (a) a texture of abstract form only, or (b) a society of communicating intelligences. These are alternatives indistinguishable and irreducible so far as a philosophy of science can decide, so long as scientific method within physical and even psychological sciences does not misuse either conception to trespass beyond its closed objective Nature.

Chapter 8. The criterion of coherence, introduced among the tests of communicability of scientific truth in Part I, has hitherto been associated with metaphysical writers who have stressed the Subjective and subordinated to it the Objective side of experience. Such a subordination is unworkable for a philosophy of science, but this truth criterion of the Idealists can profitably be segregated from their metaphysics; with certain precautions, eliminating the

traditional claims as to the 'unreality' of indefinable concepts, coherence between PROPOSITIONS instead of between ideas becomes a valuable and necessary scientific test of truth in the limited sense.

CHAPTER 9. The preceding chapters have in this way utilized an extreme Realist phase of eliminating the physical object, as physics itself tends to eliminate nowadays the 'thing' and to find more tractable the unravelling of the 'structure of relations between unnamed symbols'. Incorporating the use of 'coherence' as a test of the truth of propositions embodying those relations, rather than as the Idealists' quality of ideas, physical theory and its epistemology constitute a ground on which these types of philosopher would not be as mutually antagonistic as they have usually appeared.

Communicability and coherence of quantitative temporal relations as criteria of scientific truth, thus clarified as to their philosophical status, finally will require comparing with the QUALITATIVE communicability which may test the judgments we make as to Values, ethical or aesthetic. A comprehensive metaphysics cannot shirk the correlation of the Subjective world of such Values with the Objective world of external Nature to which scientific discourse is necessarily confined whether the scientific topic be physical or mental. The status of the imaginative and the symbolic, and their relation to the truth of logical statements, is elusive even to the mental sciences; but it will become important to decide in assessing the logically unprovable but highly significant philosophies of men like Plato or Spinoza. Agnosticism, but an 'imaginative agnosticism', may turn out to be the appropriate attitude to such philosophies.

At this point, it becomes intriguing to recall how very much a logically inevitable agnosticism, both as to objects of perception and objects of scientific knowledge, is constantly supplemented by our unverifiable mental constructs. If Part I showed how little we can prove about Nature except that quantitative relationships between unknowns are coherent and communicable, Part II indicated that our organizing of perception of any external world at

all has similar criteria of truth and limitations in verification. These justify our confidence in 'communicability of pattern', but leave no complacency as to whether supposed objects in the pattern are mental or material—whatever those discredited terms may mean. The present stage in our philosophic history may have the merit of accepting honestly an agnosticism as glad in its refusal to state what underlies science as what underlies common perception; and the agnosticism deepens, the more precise and exquisite become the patterns of the unknown which we as physicists are privileged to disentangle and contemplate. But we daily like to fancy we know something truthful about that underlying unknown, and it is healthy for us to admit that much of our judgment about it is imaginative. The exact point at which 'logical construct' and 'the imaginative' overlap is a problem for some future theory of knowledge and truth. Towards such theory, the analysis of scientific truthfulness is a most intriguing and not useless exercise upon the simplest of our mental and logical materials; the exercise offers hopes, just because it is free from the far greater complexities to be faced when we contemplate poetic vision—perhaps the ultimate insight.

Chapter 10

THE BEARING OF THE SCIENTIFIC MEANINGS OF TRUTH UPON JUDGMENTS OF NON-SCIENTIFIC KINDS

(I) AESTHETIC AND MORAL DECISIONS, AS NON-QUANTITATIVE APPREHENSION OF PATTERN AND ORDER IN EXPERIENCE

Part II has stressed the restriction upon any philosophy of science, that it has to deal exclusively with those aspects of experience which are describable in terms of a closed world not conditioned by the subjective mind. We were, for instance, unconvinced by the whole Kantian tendency to regard mind as imposing a form upon Nature, including Eddington's brilliant modernization of such tendency. But as a consequence, philosophy of science ceases to be identifiable with a philosophy of total human experience and its most general interpretation; exclusion of everything that is not quantitative and abstracted as objective, and the elimination of subjective judgments other than the automaton recording and analysing of incoming impressions, confine physics and any philosophical account thereof to that which is describable in words contained in the physicist's dictionary. In fact, the world of physics just is the aspect of experience capable of full description in words such as 'velocity', 'momentum', 'field of force', 'frequency', 'periodic time', etc., and the modern concepts replacing these. In Chapter 9, I showed to what extent a Realist epistemology of Perception and a philosophy of physics must share the same powers and limitations.

But there is no scientist, or any other thinker, who is not aware that there are other topics of importance in life and with claims to a share in any discussions of reality. Besides the judgments of Fact embodied in the language built of such terms as just quoted, we habitually and inevitably are making quite other judgments, which

concern not only Fact but Value. We no longer live in the arrogance of uncritically advancing early science, which supposed there to be nothing worth mentioning from experience except that which was describable in physical terms; indeed to-day a large number of the most expert physicists are lovers of music, poetry, art—and of their fellow human beings. That implies they are exercising judgments of Value; and these judgments, aesthetic or moral or in many senses religious, represent something as real in their experience as do the judgments of fact which they exercise upon 'Nature' and embody in the quantitative language of physics.

The problem arises, what is to replace our scientific criteria and definitions of truth, in these judgments of value? Are the latter so different that they can learn nothing whatever from scientific theory of knowledge?

The fact that the propositions of physics are confined to a language whose terms are defined in quantitative measurement, so that aesthetic and moral considerations are inexpressible and irrelevant, makes any comparison between the scientific and the aesthetic attitudes a study in analogy; the two cannot be superposed, and comparison can only be sought by peering across an unbridged gulf. But it is worth seeking. So far as the psychology of multiple personality permits, it is the self-same man who researches in science and who listens to music, though civilization will probably restrict him to an insufficient attention to the one if he is professionally employed in the other. For the sake of some coming educational schemes for breaking down this isolation, as well as for personal comfort of many, it is worth setting down here briefly a few features of the comparison, and the contrasting of the pattern which is 'true' in science with the pattern which satisfies in art or morality those other instincts than the purely logical. This topic has been more thoroughly explored in the author's *Art and Scientific Thought* (Faber, 1944).

The clue to any useful analogy between the 'truth' of a scientific explanation of experience and the judgment that some element of experience conveys Beauty or Goodness, seems to me to emerge from that word 'Pattern'. A physicist's account of experimental data was 'true' if it could give rise to identical measurements by other physicists, or could be correlated with others' measurements

by allowing for changed circumstances through the appropriate mathematical transformations. The pattern thus required the appropriate and precisely determinate stretch or twist. I called this feature the communicability of the measurements. The physicist's theory to explain the measurements was true if it similarly permitted one set of equations or functional relationships to become communicated and relevant to some different set of phenomena. The pattern thus could become visible when transferred to a new material. Coherence between the elements of these communicable patterns of logical structures was therefore the test of any truthfulness assignable to reports both experimental and theoretical, throughout the physical sciences. By such criteria of coherence we judged the approximation towards a growing and evolving 'truth' in electron theory, relativity theory, etc., criteria never conferring finality but only provisional and transient decision. Such account of scientific truth allows theory in physics to supersede theory, without any absolute 'wrong' or 'right' to be predicated at any stage, and it also allows more than one theory to co-exist simultaneously, each with its own substantiated claim to truth within its own domain of limited communicability. Examples of such co-existence were the wave theory and the particle theory of the electron and of radiation. All this contributes to a notion of physics as a pattern of logical relations, the truth criteria being recognition of the orderliness within the pattern. The recently increasing degree of abstractedness in physics, discussed in Part I, is in accord with such a view, and indeed enforces it as the only possible.

I have, in the book mentioned, developed an analogous view that a work of art is judged by the communication it achieves from artist to public, the vehicle of the communication being the structure of a pattern which in this case may be verbal or acoustic or visual, in the various arts of poetry, music, painting, sculpture, etc. The introduction of such criteria, which I here stress as bringing into analogy with each other the judgments of Fact and of Value, led in those writings towards a tendency to demand that a work of art should arouse a response in the hearer or reader or observer, the response being essentially some coherent pattern of feeling. In such communicable stimulus, the conventional requirement that the work of art shall 'copy Nature' or 'represent some likeness

to something' is eliminated; instances were drawn from Chinese, Romanesque, and modern arts, where a work fulfils the requirement of communicating coherent feeling without necessarily 'looking like' a represented object. Art thus acquires quite abstract characteristics and merits through its symbolisms, just as did the science whose electrons do not 'look like' anything at all in perceptual experience and yet are as real as need be.

There are two essential differences between the 'true in science because communicable and giving rise to coherent patterns of functional relationships' and the 'adequate in art because communicating coherent pattern of emotional states from artist to public'. (a) In physics the pattern is one of quantitative measurements, while in art the pattern is more subtle, and, employing emotions and not merely sense-data, it is rarely to be laid out for universal inspection in descriptive terms. (b) As a consequence, whereas the responses of the physicists to a research are precisely correlated, each worker finding the identical measured data when he repeats the experiment so long as transformations take care of altered velocities, etc., in art each separate recipient of the artist's communication exhibits some different response. These multiple responses to a single work belong to the infinite variety of emotional and imaginative and recollected backgrounds of our several minds. We all, according to our own private history, find something different in our experience of a Rembrandt painting; also of a Mozart Quartet or a Shakespeare sonnet or one of the sculptures of Chartres cathedral. The aggregated pattern in the whole assemblage of all our responses must be coherent, but may be exceedingly variegated: no simple quantitative transformation like the Lorentz relativity of physics can turn the aesthetic reaction of one personality into that of another.

It might well be argued that ethical criteria are also those of pattern, 'goodness' being the quality of contributing to harmonious interlocking of free behaviour among individuals and judged as communicable coherence of intention and practice.

When these differences between scientific and ethical or aesthetic are carefully observed, between the quantitative and the more subtle qualitative, or between the infinite shading in responding minds of the art lovers and the precisely correlated recording minds of the physicists, there remains the underlying similarity.

The sciences as well as the arts seem all to be attempts at reducing individual experience to some communicable pattern. Whether the 'real' thing in the pattern is the abstraction of purely logical or mathematical form, or the structure of rhythms built upon visual or auditory or other periodicities, or must be referred to the psychological interlocking of emotion with inferences from perception and memory, depends upon what region of experience is being exploited. The judgments may be solely of Fact, if we are being scientific, or of Value if we are functioning for the moment as artists or moralists: a metaphysics, but not a philosophy of science, must take into account all these kinds of judgment, and therefore cannot ignore the subjective as science must, nor regard the external world as a closed system of Nature. Towards any such metaphysics, the clue that sees in physics and in the arts the growth of communicable patterns of logical forms or of mental states may serve as tentative but suggestive guide, if the above restrictions to similarity are carefully observed. Truth in science will be found to have counterpart in the mental structures of ethical and aesthetic experience, which are mutually illuminating though neither must be forcibly imposed upon the other or allowed to distort the other kind of judgment.

(II) THE INTERNAL AND EXTERNAL WORLDS, IN PHILOSOPHY, SCIENCE, AND IMAGINATION

In distinguishing judgments of Value from scientific judgments of Fact, and noting that the former introduce subjective considerations alien to the closed Nature or physical world, it becomes inevitable to ask whether any proposition conforming to our scientific criteria of truth can ever be formulated concerning the Subjective side of experience. Science is mainly concerned with investigating the environment of the thinker, can it not bring the same methods to bear on the thinker himself?

Opinion that such is never possible must not be taken as a mere oblique variation of the jibe 'psychology is not a science'. Actually psychology can be a science and often is, though much that has passed under its name has not reached, or does not care to reach, a very high standard of scientific rigour or even honesty. But the decision to which I need to draw attention here is more drastic,

and not open to reversal through improvements of technique and discipline. For just as physics 'externalizes' its world, regarding it as a closed system of Nature observed without interference on the observer's part, so psychology demands a similar attitude: in spite of the 'mental' character of this particular objective world, the study of it must still exclude much of the subjective mind. This is because psychology can only achieve scientific reliability and orderliness by adopting the same criteria of coherent communicability as raised physics to its present status. This requires mental facts to be 'externalized' and abstracted into a closed Nature, untouched by the preferences or aesthetic and moral judgments of the investigator. Even when the most introspective researcher is analysing and assessing the phenomena describable as 'aesthetics' or 'ethics', during his scrutiny he must abdicate from his status as whole human being, and act as impartial recorder of mental fact, renouncing for the occasion any exercise of judgment as to whether he would have called the facts pleasing or good. The mind, as investigated by the psychologist, is under illumination *in vitro* rather than *in vivo*, and a treatise on the emotions must be as unemotional as a treatise on physics, if it is to claim the status of scientific truth.

In this way the Behaviourists, for whom actions and reactions constitute the entire data and material of psychology, and the 'mind' is an imaginative construction which may be dispensed with, are correctly carrying scientific method to its logical conclusion: parallels between their approach and that of Dirac in physics and Russell in his theory of Perception are very instructive. But Behaviourism is a scientific technique. It is no more a ground for metaphysics than was theoretical physics or realist epistemology, both of which eliminate the subjective personality in order to free their hands for their legitimate duties to an objective world.

The subjective world includes much that we call spirit or character, beauty or moral worth; these are terms in whose vagueness we attempt feebly to enshrine elements of experience which we all accept tacitly as real but which are not compressible into the externalized worlds of physics or of psychology, anthropology, and sociology. The subjective therefore only presents itself to metaphysical speculation with the status of an imaginative construct. But much of this essay will fulfil its purpose if we have the honesty

to recognize that the ultimate conceptual objects of physics, and even much which underlies common perception, have logically no firmer status.

The moral or spiritual or aesthetic characteristics of experience can all be readily dispensed with in working to the ideals of scientific truthfulness, because the relevant pattern is most communicable in the form of abstractions; but a metaphysics which omitted to take account of our valuations as well as our ordering of facts into those physical and psychological abstractions would be idle nonsense. Metaphysics, charged with the duty of synthesizing the internal world of aesthetic and moral judgment as well as the logical patterns of external physics and externalized psychology, has to rely upon the self-consistency of its propositions and can scarcely hope to provide anything so convincing as the simpler patterns of the isolated mental and physical sciences. It has certainly failed so far to give final conviction, perhaps because it has so often tried to model the universe upon either 'material' or 'spiritual' pictures without recognizing the fragmentary character of any such importations from Objective or Subjective alone. Hume and Berkeley showed from opposite standpoints how much of either internal or external world can well be dispensed with, and the Russell theory of Perception in our earlier chapters again demonstrates how much of our discourse is bound to be 'logical construction'. But is such construction mere myth, in the sense of being necessarily false or misleading? We probably all believe in the myth of there being an external world beyond sense-data, though Russell has shown it is inaccessible to proof. If we thus admit our daily use of the imaginative in Perception, and also in the 'ultimates' of physics, which are justifiable enough by the criteria of communicability, there will be other concepts claiming imaginative but honourable status too.

The glimpses of such concepts, throughout the history of philosophy, are tantalizing in their offers to synthesize the internal and external worlds of Subject Knower and Object Known: 'Form', 'Structure', 'Spirit', may be less open to objection than the Idealists' 'Absolute Idea', but all are vague terms attempting vainly to cover our ignorance, and yet to embody the universal conviction that partial and incomplete patterns of physical and mental sciences and of the arts may represent to our crude intelligence some more

comprehensive pattern. Even the genius of a Plato or Spinoza or McTaggart fails to make that most ultimate of patterns more than very dimly comprehensible, and the metaphysic of the future, as of the past, is never likely to survive destructive analysis.

One way of approach is to speak of 'Action' instead of 'Thought': Bergson tried this, but imposed an unintelligible brand of mysticism upon his logic. That the Marxist philosophers of modern U.S.S.R. adopt such a programme is hopeful for the future, if they succeed in emancipating themselves from the hasty materialism which they inherit from too literal readings of Victorian science by their pioneer.

But neither Marxists nor any other philosophers, trying gallantly to comprehend the internal world of Valuing Subjects with the objective world of mental or physical facts and structures, must pretend that they have lost the need for the imaginative approach, or even for the mystical, as inevitable antithesis to the scientific but in the end complementary to it and not irrevocably antagonistic.

Mysticism, too often grossly overlaid by a tendency of the emotions to drug the intellect, can rightly become a recognition that there are limits to 'knowing' among the duties of the mind: there are genuine and important experiences, in which we quite honestly sacrifice to the love of beauty or moral character, and which we cannot justify or even rationally describe in logical terms. It is cowardice to ignore them and hypocrisy to pretend to despise them; a controlled and highly disciplined imagination, often called the poetic, is the only legitimate mode of approach. Truth in the scientific sense is here unattainable, as the language of the communication is not adaptable, but the imaginative treatment is not necessarily delusive or totally devoid of significance.

(III) TIME: IN PHYSICS, AND IN THE SIGNIFICANCE OF MEMORY AND IMAGINATION WHICH REQUIRES A PHILOSOPHY TO ACCOUNT FOR MORE THAN THE QUANTITATIVE ASPECTS OF EXPERIENCE

There is one special instance of this requirement that a metaphysics shall include judgments not expressible within the pattern of an abstracted external world; I refer to the particularly intract-

able philosophical questions arising from the use of the word Time.

So far as the pattern of functional relations is concerned, or the logical structure within which our definitions of truth are valid, temporal order of an individual's experience of events seems to be the irreducible characteristic of sense-data upon which physics and a philosophy of science must build. In an earlier book (*Time, Knowledge, and the Nebulae*) I have discussed as important Milne's view that much of the physical pattern can be reconstructed in terms of the correlation of these temporal orders alone; but I also stressed that this affords no evidence as to whether in a philosophy of Value judgments any such essential reality of temporal fact remains the dominant feature. An inescapable ambiguity cannot be resolved in the present state of science and philosophy. Firstly, our knowledge of the external world is essentially a cohering of logical forms, in which the one variable that cannot be transformed away is that denoting the serial order of an observer's temporal experience in his own local situation; the basic fact of all our destinies is that we cannot reverse that order. Secondly, there is equally urgent upon our attention the other kind of fact, for which the language of physics has no expression conferring truth or false opinion; we all do truly create new situations in our character and personality, by seizing from the irrevocable and passing events their glory and terror and making from them the tranquillity and regret of our future—the indisputable sense in which we turn the ephemeral into the more lasting and discover in each of us the mastery over Time.

But to confer any truth upon statements of this latter kind, which in one sense make the past and the future as real as the present, and in another sense remove the sting from Time our enemy, memory and imagination must supply data as well as perceptual experience. This eliminates such topics from the physical analysis of the external world, and requires the exercising of a poet's or even a mystic's duties, which I referred to as complementary and never overlapping with the work of the scientist and logician.

The attempts throughout history to satisfy simultaneously scientific and other instincts, and to claim truthfulness all along, have clogged philosophy with much nonsense about Time, ever since it was recognized to be the most difficult and intriguing of all

topics. It will illustrate some of the distinctions between the physical and quantitative and the metaphysical and qualitative of this chapter, to trace a few guiding threads through this tangle of the philosophy of Time.

The primitive notion, that Time can be called a 'thing', is a notion submerged in a multitude of poetical preoccupations with the tragedy of the irretrievable and ethical preoccupations with the urge of rising to passing opportunity; but it achieved physical expression in the Newtonian concept of an Absolute Time, evenly flowing and completely detached from the activities and even the geometrical situation and motion of any observer. Leibniz in the same century recognized that rather than talk about Time as a thing, we ought in science and logic to talk about Time as a relationship. Delayed by unfortunate modelling of a concept of Time upon that of Space, which too easily becomes materialized into an imagined Ether, the notion of Time as a relation only began to penetrate scientific language and thought when the Relativity of Lorentz and Einstein showed precisely how observers' estimation of temporal intervals and spatial intervals are not unique but conditional upon their motions. This enforced a recognition that measurements of the separations between distant 'events' are not absolute but relative: the partitioning of the interval between two events is more space-like or more time-like according to situations and velocities, and so varies from observer to observer. No one observer has stronger claim to truth than the other, truth becoming a question of correlation. This was the initial classic instance of communicability as defining truth in my theory of Part I. The role of physics is to formulate the transformations, for example of the Lorentz type for uniform motions, which enable communications to become coherent, and therefore uniformities to be abstracted from these infinitely variable temporal and spatial circumstances.

Whitehead's logic, summing up the passage from spatio-temporal perception to the physical concept of Time, adequately removes the notion of the latter as a 'thing' from physics and philosophy of science. I have repeatedly drawn attention to the grossly misleading metaphysical implications which arose from misuse of Minkowski's fusing of time and space: this fusion is a useful geometrical picture of the Lorentz relations, but nothing more. Its intrusion into metaphysics led Alexander and a host of lesser philo-

sophers to lose trace of the essential temporal orders in the experience of individuals, submerged in a spurious unity 'space-time' which can only be a geometrical convenience and not a 'substance'.

These developments in the logic of physics, and their important sequel in Milne's recent work which attempts to re-establish temporal order as the foundation of physical reasoning, cannot be ignored by current philosophy; but their epistemological significance must never again lead to a blind metaphysics. It is in the light of this caution that we also rejected Eddington's superposition of mental upon physical factors. Indeed the logic of science emerging from the relativities of Lorentz, Einstein, and Milne gives no support whatever to any use within physics of metaphysical concepts of Time. Kant, who treated Time as a form of intuition imposed by the mind upon an external world, and the Hegel school with Bradley who claimed that antinomies in the self-consistency of temporal definitions could prove 'time is unreal', all carry a somewhat fantastic air after the precise but limited propositions which can alone conform to our definitions of truth subsequent to the era of relativity physics.

The anomaly that metaphysical conclusions about Time have opposed each other without any possible conclusiveness, can only be clarified by the distinction which I have been drawing in this chapter and summarizing in the preceding section (II); this distinction acknowledges that another world of Values, and of the activity of the Subjective mind, must be taken into account in any final metaphysics, besides the world of scientific truth externalized from that portion of experience which abstracts sense-data without commenting thereon. We shall not assess correctly the Idealist philosophers to whom Time is not the final word, such as Plato, Spinoza, McTaggart, nor any poetic vision of the Timeless, until we realize that in physics and in philosophy of science we are not talking the same language as was talked by these seers and speculators, and are not referring to the same aspect of experience. Both worlds are highly relevant to human destiny.

Two prolegomena may be stated as essential to any future metaphysics of Time which might claim to comprehend both the true patterns of physical reasoning and some of the idealist's and the poet's vision: they both arise from the view of criteria of truthful-

ness evolved in Part I, and compared with Realist epistemology in Part II. Indeed they are particular cases of cautions already formulated in general terms.

Firstly, no conclusion as to reality or non-reality of Time can be drawn, as Bradley and the Hegelians supposed it could, from discovery of ambiguities and inconsistencies in the definition and analysis of the concept of Time. Whenever such inconsistencies are exposed, they call for an improvement in logical technique to reconstruct the edifice, not for a metaphysical decision that there can be no meaning at all underlying any such conception. I have quoted Russell as demonstrating how modern research could invert the Hegelian attribution of 'unreality' to Time by removing its inefficient definitions of infinity.

Secondly, there is a corollary from our definition of the world about which scientifically true propositions can be formulated: in order to reach the requisite degree of coherence and communicability, all activity of the Subjective mind and all meaning to judgments of Value, aesthetic or ethical, must be rigorously excluded. It follows that, unless we are prepared to assert that the subjective is MERE myth, there is some other world of discourse to which such topics are not irrelevant, and which is not of identical definition with the physicist's closed external world of Nature. The reduction of the subjective world to erroneous construct, and not solely to imaginative construct, is an unprovable possibility which would be the inverse of solipsism and hardly less unconvincing. The logic of science sees no reason for shirking that other world of Values, though its relevance to impartial analysis of the closed world of Nature is nil.

In that world of Values, temporal order may or may not have the simple and controlling significance which it undoubtedly has in the physical world. The need to take account of imaginative constructs and of judgments that a situation has goodness or beauty, imposes a language which has no place in a book such as this concerned with scientific truth. But it would be rash indeed to leap over the unprovable and assert that the imagined is always the denial of the real, not merely its complementary antithesis. This is especially so in discussions of Time. I have in the other book referred to (*Art and Scientific Thought*) stressed the somewhat parallel development of the imaginative and the scientific judg-

ments, each in its own situation among human experiences; in no topic more intriguingly than that of Time does any comprehensive metaphysics require the one as well as the other, and in no topic is there more danger of imposing logical sanction where the imaginative is the relevant and invoking imaginative sanction where the logical is the only trustworthy.

(IV) McTAGGART'S TEMPORAL AND NON-TEMPORAL SERIES

One philosopher of the recent generation, McTaggart (d. 1925), carried to brilliant extreme a development of the kind of work quoted in this chapter: a novel way of assessing it might compare healthily our aims and possibilities and criteria for truth, as regards world of scientific method on the one hand and world of values and individual imaginative constructs on the other. The comparison may reinforce my suggestion that a proposition definitely incapable of proof when stated in reference to the physical world of Nature, might nevertheless be not wholly untrue, and might be logically neutral and of some imaginative importance, in branches of philosophy not exclusively tied to the abstracted external world.

It is arguable that McTaggart's philosophy, and *a fortiori* the many less meticulously careful Idealisms traceable through many centuries, will stand or fall by their treatment of Time; since that topic epitomizes the strength, limitation, and possible need for supplementing, of the scientific method of reaching 'truth' in our explanation of experience.

One must remark that McTaggart himself would have rejected vigorously the suggestion that novel conclusions as to the ultimate nature of things cannot be obtained or rigorously proved by methods of pure logic. That Broad and others have succeeded in shredding destructively the steps of his argument would have appeared to him—if he accepted their own steps—as annihilating and conclusive. In fact, to assign any importance in the hierarchy of truth to statements judged imaginatively or symbolically but not provable logically, would to most of the great philosophers have been heresy; and yet for that heresy I am here putting forward a defence. This is now pleaded in full recognition of all metaphysical systems being

necessarily stigmatized as imaginative and unprovable constructs, since we have already noticed that the same can be said of many external devices in the universe of science and of perception. Nor will any easy approach to acceptance be attained by making a metaphysics pass aesthetic rather than solely logical scrutiny. For the comparison between scientific and imaginative approach to genuinely truthful statements might well be somewhat analogous to saying: 'The persons in the *Odyssey* or in *King Lear* were never objects of anyone's perceptual experience, and factual statements to be judged by our criteria of scientific truthfulness cannot be made about them; and yet the *Odyssey* and *King Lear* do contain some of the most important truths of which we have ever been made aware.'

The work of McTaggart, as that of Plato and Spinoza, has in this way some of the subtle validities of a work of imaginative art, expressing important aspects of a legitimate attitude to the problems of existence—but in the form of seemingly logical structures instead of any of the more conventional media of aesthetic appeal. These aspects of experience may comprise as adequate an approach to truthfulness as that expressible in the network of relationships forming the fabric of physical theory or the network of objects forming the 'logical construct' which might unprovably underlie perception.

Neither physics of Nature nor psychology of Perception can include the relation of Subject to Object in knowledge, and both are therefore one-sided and partial: McTaggart's does include the subjective, so it is unlikely to be as watertight a logical system as a science which has only commitments to an abstracted half of experience. It is certainly, from the all-embracing scope of its title, 'The nature of Existence', precluded from verification in the way that a quantitative pattern of physical relations is verifiable. Tragically, it courts rejection when the logical gaps in its argument are exposed, without being brought to stand its trial as would be the right of the vaguer and more obviously emotional appeal of a picture or a poem. Perhaps a more correct analogy is to some musical structure, which by the logicality and reasoned pattern of its Form has profound effect through the imagination of a hearer who is responsive to abstract structure. For what is the counterpart of 'truth' in music? Not a virtue to be judged by our criteria of

scientific verification, but not to be stigmatized as misleading, and actually recognizable by different but rational tests of 'communicability, qualitative and involving coherence between Value judgments'. Someday we shall learn the discrimination to judge the formally logical but indeterminate, by an aesthetic decision which nevertheless avoids the pitfall of reasoning from the desirable to the believed. It will then be not either inadequate or undeserved to appraise McTaggart with Plato and Spinoza.

Towards an understanding of 'Time' such as might, within these unusual restrictions, be possible, McTaggart offers an approach which is not merely the traditional Idealist's assignment of 'unreality' to any concept in which inconsistency can be detected. Unlike his predecessors, he developed also a precise pattern of ideas to show just how a timeless sequence might be held to replace the inevitable temporal aspects of the 'order' in which we experience events. Treated as a pictorial pattern in logic, his 'Timeless reality' may thus have the imaginative status to which our 'external object and closed Nature' have been confined in this essay, and it may be neither more nor less significant than those common conventions, when we try to decide our coming-to-terms with our environment and our temporal destiny.

His representation of the fundamental ambiguity of Time, namely that we cannot reverse the progress of experience and yet that some of the most real aspects of experience are incompletely stated in temporal terms, is in the form of an interlocking relation between series. An 'A' series describes the passage from past through present to future, and its terms are therefore continually changing and passing into one another; a 'B' series is constituted by the relations 'earlier than' and 'later than', and its terms are thereby constant and persistent. A 'C' series comprises the real relationships of which the A and the B were partial appearances only, and the character of the relationships within the C series is the character of 'logical inclusiveness'. Progress 'in Time' is thus a partial and incompletely true version of an advancing inclusiveness which is timeless and real.

There may well be, in this distinction, the germ of a notion capable of far-reaching consequences; for the A and B series seem to me to bear remarkable resemblance to some of the nature of the scientific approaches to Time, respectively from the mental and

the physical abstracted sides of experience. It is possible that something like the notion of the C series may become capable of describing aspects of experience which involve Value judgments, which do not come under physicists' or even psychologists' definition of truth and are notoriously unamenable to description in terms of temporal order.

The apparent barring of development, by the frustration of our desires to stay the transient, may come to more rational account in the human significance of the past if it is rewritten as a comparison between McTaggart's several types of serial order: the temporal sequence of all observable events, which alone permits a communicable physics to become one of the ineradicable preoccupations of the civilized mind, may perhaps be seen in more nearly correct perspective with the poetical and ethical interpretation. For we all pursue, scientists and non-scientists, the inescapable and urgent need to build the more permanent in our spirit out of the most transient of materials; and the elusive meaning of the recollected and the imagined must be taken into account by a philosophy whose data are not confined to the physical or temporal order. The past does survive in the present, alive and not merely embalmed, and McTaggart's pattern of interlocking series, temporal and non-temporal but real, may contain a hint of how such syntheses are someday to be seen.

In fact, if the characteristics of temporal experience emerging from physical and psychological science are summed up logically in the properties of the B and A series, the significance omitted thence is inevitably reserved for expression in some such form as the C series; the essence of any growth is the extraction of the characteristics of a future from those of a past, and in a highly developed mind this is a creating of new situations through the exercise of imagination and recollection upon situations which as past are no longer real. All mental growth is therefore representable as a series of states of increasing inclusiveness, and the passage of time does mean the contribution of an A and a B series into something, ordered but whose order is not in the same sense temporal. The vulnerable and unprovable steps of McTaggart's picturing of this in his pattern of interrelated propositions, have therefore a vital significance not calling for hasty rejection, but calling for further research which must be both logical and imaginative. Metaphysics

must no more ignore the imaginative now that some of its data are scientific, than it ought to have ignored the logical when it had only the poetic to draw upon. Now that the precise but limited truth of scientific method has brought so much understanding of external Nature, the necessary distinction of the scientific judgment from the aesthetic must not delude us into regarding as either hopeless or unworthy the duty of going on where Plato and Spinoza and McTaggart left off.

(V) THE SIGNIFICANCE OF TIME IN EXHIBITING AND RESOLVING THE ANTITHESIS BETWEEN SCIENTIFIC AND POETIC MEANINGS OF TRUTH

The foregoing subsections of this chapter, supplementary to the logical and epistemological aspects of scientific truthfulness and knowledge which had been the book's main concern, may now introduce a summary of the possible contributions towards clarifying one of the most fundamental antitheses than can haunt any reflective mind. Assembling in brief the conclusions of those subsections, we find in (I) the reasons for comparing and contrasting the criteria of truthfulness in science with the non-quantitative appreciation of pattern and orderliness which we call moral and imaginative judgment. (II) We find that the inaccessibility of the subjective aspect of experience, even to psychological method, enforces the employment of imaginative constructions in any metaphysics of an external world supposed to underlie perception; this also confers upon more mystical apprehension of Values moral and aesthetic an individual sanction which is not necessarily delusive, though inherently not communicable in any scientific sense. (III) For this reason, legitimate attitudes to the significance of Time must include firstly the scientific, where the temporal is the reality which is the basis of all physics, but secondly the imaginative, without which the physically adequate is philosophically incomplete. (IV) In the particular case of McTaggart's metaphysics which regarded Time as 'unreal', there is logical inadequacy in his extension of the traditional idealists' proofs, but there may survive an imaginative or poetic significance whose validity is not to be rejected as 'untrue' when assessing the subjective creation of value-judgments.

The so-called problem of Time is therefore of peculiar importance to our inquiry for any relation between scientific practice and the legitimate criteria of truth and knowledge: it is a problem demanding the most rigorous logical analysis as yet cast up by physics, but it also indicates decisively the boundaries of such analyses and the requirement of imaginative but critical supplementing of scientific method before we can reach balance in any comprehensive interpretation of experience.

What then is the antithesis which emerges from any considering of Time's meaning, in the light of the scope and limitations required for scientific criteria of truth?

(a) The antithesis appears both in our practical organizing of civilized life and in the theoretical assessment of its possible destiny. The practical aspect is to-day obvious and pressing. For the advances of a physically directed technology are often claimed to 'annihilate time and distance': they even introduce the imminent risk of terminating abruptly all our hopes and fears, if politicians do not come speedily to recognize that the scientist conscripted to war brings with him a sword too many-edged for world-safety. He has under pressure devised weapons which cannot be shelved like the mere rifle that he shared with his non-scientific neighbour when both were slaves to be forgotten after use. But the mastery of annihilation or even of communication is not a mastery over Time, and may be a more subtle and profounder slavery. The shortening of transit of journeys and messages accentuates the intimidating development that the individual's time for achieving freedom of personality vanishes the more rapidly. The expansion of adolescence is telescoped until there is no time left to study or appreciate or love or to cultivate the life of spirit or intellect, and the more frenzied the acceleration of civilization the more irretrievably its control slips from us until instead of training an equilibrium of decisiveness we degenerate into the merely haphazard.

Nor is the tyranny of unconsidered acceleration confined to the young, or even to the modern age; the inexorable transience of the lovely, the fading of treasured memory and the sting of regret over lost opportunity, have inspired poets and moralists with their most clear-sighted but most impotent sense of tragedy. This tragedy is intensified rather than relieved by the contrast of our physical control over every other aspect of Nature but Time.

(b) Physics, with its technological following, is not merely the ambiguous demon of the practical situation, enforcing this antithesis between gain in speed or hastiness and loss in peace of mind; its subtler outlook upon theory of 'passage of time in the external world' I have elaborated in the earlier book on Time and Knowledge already referred to. The only point essential for the present discussion emerges when our criterion of scientific truthfulness insists that the 'real' in any valid analysis of an external world is just the temporal. For whether Milne's new treatment of time in physics, expounded in some detail in that book, be found ultimately to be correct or erroneous, there is no doubt that physical science is always to be written down in differential equations with a time variable: however undetermined the symbols of recent atomics, at the bottom of all the formal relationships we shall discover time. The individual observer's serial order of events perceived has become the ultimate datum of science, and the selection of the pattern for rendering communicable those orders is the 'discovery of truth' which used optimistically to be called the uncovering of the laws of Nature.

Materialism, in the sense of any belief that we 'know truly' a stuff of which the universe is made, may nowadays be discredited in the manner I have outlined in an earlier chapter; but as dark or darker a thesis confronts the humanist when the physicist's universe of matter has dissolved into a formal pattern whose elements are simply time orderings or relations of succession. The exquisite poetry of Bertrand Russell's *Free Man's Worship*, in common with such philosophies as expressed in I. A. Richards's *Science and Poetry*, used to be called a pessimism in claiming that science has put an end to the most hopeful visions of its universe; to-day such claims seem somewhat fanciful, and we realize that only complacency, not the hopefulness of human initiative, need be incompatible with scientific outlook. But although Russell and Richards quoted an obsolete materialism, the inexorable in the physicist's Time is no less merciless than the earlier physicist's 'dead matter'. We shall no more come to terms with Time by facile ignoring of its inescapable meaning for the physical analysis of the external world, than we shall be justified in surrendering to a Time whose significance may be confined to that external Nature.

In the light of the restrictions which we have been drawing

around the precise notion of scientific truthfulness as coherent communicability, what constitutes the second half of the antithesis? Is there a knowledge which, besides making Time the ultimate reality in scientific philosophy, also recognizes truth in any sense in a statement that human endeavour can rise superior to transience?

In searching for that other aspect of Time, any investigator must first classify even the most inadmissible attempts which have been made to deny the reality of Time. These attempts range from the magnificent and nearly convincing logic of a McTaggart or a Bradley, right down to the cheap religions which cross-breed from degenerate descendants of Neoplatonism and an emotional fancy for grafting oriental cults on to western sentimentality. They all claim that there can be truthfulness in some argument of escape from temporal experience, rendering the latter inherently delusive. The more logical, honest and thoughtful students of Plato, Plotinus, Spinoza, Hegel, Bradley, Bosanquet, and of McTaggart the acutest mind of all, argue from a metaphysics that assumes a species of universe which must be multifarious manifestation of a single unity and that unity mental. I have earlier stressed some points at which such a metaphysics is always vulnerable, and the Cambridge logicians' criticism of these philosophers' logic has been classical and unanswerable.

The more numerous class contending that Time is unreal have been frankly mystics, and have rarely been admitted or claimed to be philosophers: they have not tried to wrap up in logical sequences an intuition or a faith better classified as imaginative whether supplementary to the scientific or hostile to it. Catholic saints, Chinese modifiers of an otherwise ill-proportioned Buddhism, and the great Chinese visionaries of the earliest Taoist cultures, have simply stated that they find themselves able to train a disciplined sense of unity with Nature which can liberate them from Time. Hallett's exposition of a Spinozistic 'Aeternitas now' bridges the gap between these mystics and the more formal philosophies.

Since mystical experience is not susceptible of precise description, it is never communicable in the sense required for a scientific statement to become 'true' in our definitions; nor can mysticism claim the validity criteria of communicable art, since it is essentially

formless and not expressible in a pattern or structure which alone could transmit genuinely aesthetic appreciation. The unreality of Time must remain for ever for each mystic his own secret, however legitimately convincing it may be to him alone.

It is possible that the escape from temporal limitation claimed by many idealist philosophers, for instance of Platonic or Hegelian tendency, is actually based upon such mystical conviction on the part of these individual thinkers. It is rare, and perhaps only in the writings of McTaggart, that the logical supporting argument becomes almost convincing to anyone who is not himself of similar mystic persuasion, and even McTaggart's most brilliant logic has not survived Broad's probing. We shall not have much difficulty in recognizing the justice, if it is as mystic rather than as logician, and not less honourably, that McTaggart acquires an unassailable status in philosophic history.

At the extreme farthest removed from such rigorous honesty and intellectual power, there are the superficial religions manufactured to-day in England, America, and other countries, ministering to an uncritical temptation to copy anything oriental or venerable: these pseudo-philosophies or pseudo-theological systems, claiming to be new science or anti-science, are mystical but not content therewith. So they lose their footing in both worlds when they start to argue, and might better abandon propaganda in favour of the silent and private belief to which alone they are entitled.

In extracting the rare genuine philosophy from centuries of such fantastic speculation about Time, I described in subsection (IV) McTaggart as the only philosopher to formulate a definite relationship between timeless series and the apparent sequences of our temporal experience; in suggesting that he may have imaginative sanction even in his logical inconclusiveness, we can only hope to elucidate such sanction by observation of psychological fact. On what sort of fact could be founded any kind of imaginative supplement to the scientific truth which had made the temporal the most real and unalterable feature of Nature?

It is an observed fact that different personalities have certainly made greater and lesser uses of their ethical and aesthetic creativeness in handling the transient situations of our common experience. The passing of the latter they cannot arrest, but its significance

some of them have seized and built into a growth of novel human character and power. By accepting the brevity of delights as well as the terminable duration of misgivings and terrors, such men attain command over their own reactions thereto, and they create new experiences through such self-discipline. This is in a genuine sense an acquired control over destiny. It is no idle fancy, but a truth poetic as well as ethical, to say that they have built the lasting out of the passing which is thereby not lost. It is only not a truth scientific, since a quantitative estimation of their achievement, and even a logical demonstration of its existence, are necessarily forever lacking.

Man lives not solely upon the truth of his sense-acquaintance, or even upon the more highly organized truth or coherent communicability of logical pattern which I have been defining as scientific. In fact, even within science, as I have described in earlier chapters, some mental constructs which must be termed imaginative are transiently employed to embody the mathematical and logical forms which are the only valid pattern of physical reality. Any pictured external world is an erection containing much that is beyond logical verification or that could claim the scientist's criterion of truth. If the same scientist's organizing of his internal world carries him to sufficient moral stature, he is continually building the more durable by selecting in memory and imagination from among the most fleeting of his experiences.

But to estimate just how durable his creation will be, is perhaps to dream: such would be a venture of faith and not of science, and would depend upon that most unprovable but ineradicable sense that whatever we most lovingly construct is never a total loss, and that there may be a personal response from our universe for those who discipline themselves to hear it. That kind of faith is older than the orthodoxies and wider, and will survive them. There is nothing whatever in the scientific truthfulness I have defined in this book to conflict with such a faith—but the latter must not demand the former's support, only its strict neutrality. Faith no longer needs to face logic's hostility, so long as it does not trespass in the latter's territory; for a disciplined and controlled imagination is not so much a contradiction of the scientific attitude of mind as complementary to it. It is by a highly trained imagination that the exploring physicist fills in a necessary but shifting content,

of which only the framework or logical structure is provable knowledge: it may well be by imagination that ordinary experience as well as the specialized experience of the physicist must picture any external world beyond the actual pattern of sense-data, according to the view which I adapted from an older realism of Russell's in Part II. It is more obviously, but no more rightly, to be called an effort of imagination, when humanity defies the tyranny of Time by accepting unshrinkingly the truthfulness of communicable physics as rigid time-pattern and yet insisting on creating ever the new out of the passing and transient. Poet, lover, and worshipper, who by their sacrifice for some ideal which they regard as not temporary can actually set themselves to retrieve the loss of passing delights, are the only ones among us to realize Aeternitas within their own time; but they must not expect a logical as well as an imaginative triumph. There is not to be a science of theology—or of poetry—in the sense in which I have been investigating the possible meanings of scientific truth.

From these considerations it becomes conceivable that the richest contribution towards theory of knowledge, from the truth criteria of modern physical sciences, will come by their revealing of the status of Time as basis of our organized acquaintance with the external world of Nature. For it is that status which will force idealist and realist alike to face the antithesis between the logical and the imaginative, both sides of which must be accepted in making our peace with our destiny. We shall indeed find in the logical world of structure investigated by physics the supreme beauty of Significant Form, as stirring as any discovered or created in any science or art; but only if the implied meanings of Truth and knowledge are rationally criticized and are not taken to exclude from the exercise of our minds a disciplined audacity of the poetic imagination. It is as preliminary survey for such rational criticism that this book has set out to uncover some of the difficulties and the exhilaration of the problem of truth in science.

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